THE UNIVERSITY OF ALBERTA

RELEASE FORM

NAME OF AUTHOR R.D. Winkler

TITLE OF THESIS Watershed Stratification for Flow Prediction

DEGREE FOR WHICH THESIS WAS PRESENTED Master of Science

YEAR THIS DEGREE GRANTED Spring, 1980

THE UNIVERSITY OF ALBERTA

Watershed Stratification for Flow Prediction

by

©

R.D. Winkler

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF Master of Science

Forestry

EDMONTON, ALBERTA

Spring, 1980

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled Watershed Stratification for Flow Prediction submitted by R.D. Winkler in partial fulfilment of the requirements for the degree of Master of Science.

Abstract

This study involved watershed stratification, as a tool for hydrologic interpretation, based on data collected during biogeoclimatic classification. The Tri Creeks experimental watershed, located approximately 40 km southeast of Hinton, Alberta, was selected as the study site. Its three basins; Wampus, Deerlick and Eunice Creeks, were stratified into two units of hypothesized hydrologic homogeneity, based on ecological data. The designated units were basically a saturated and an unsaturated zone. These units were then evaluated in terms of local water balances and their status as contributing areas to stormflow.

The water balance approach was used to calculate runoff from both zones, in all three basins. The runoff values obtained were compared to actual flow measured at the outlet of each creek. Estimated runoff was within five percent of the actual for Wampus and Deerlick watersheds and roughly 30 percent for the Eunice Creek watershed. It was hypothesized that a portion of the residual noted in the latter calculations was due to leakage and/or overestimation of precipitation inputs to upper Eunice. On a unit-area basis, it was further noted that water potentially available for flow from the saturated zone was 6, 7 and 12 times larger for Wampus, Deerlick and Eunice Creeks respectively, than that from corresponding unsaturated hillslope areas.

Hydrologic response indices were calculated for all basins and hydrologic units. Response values of 50 percent

were obtained for the saturated zone and 60 percent for the unsaturated area.

The saturated zone in each basin was assumed to be the primary area of stormflow generation. The rational formula was used to predict stormflow based on the areas mapped as saturated, or contributing. Results of these calculations indicated that for the majority of storms, peak flow was overestimated. It was thus hypothesized that the mapped contributing area was an overestimate and that this zone contracted over the flow season. Vegetative associations, however, appeared to delineate the maximum extent of saturation which would include an intermediate zone of periodic saturation. This zone would expand in direct proportion to the contraction of the actual contributing area.

Finally, regression analyses were conducted to evaluate the significance of contributing area theory to peak flow volumes. Spring flow appears to be influenced to a large extent by parameters not considered in this analysis. However, 90 percent of the variability in summer flow was accounted for by antecedent conditions, precipitation and the hypothesized contributing area. It appears that the contributing area for summer stormflow can be approximated by saturated zone delineation using vegetative association data. The precision of zone delineation might be increased through examination of species composition in the intermediate zone, defined as a transition between the

saturated and unsaturated zones.

It was further suggested that a study involving actual field measurement of saturated zone contraction over the season, as well as actual moisture movement, would allow a greater understanding of the interaction between zones and increased accuracy in runoff predictability.

Acknowledgments

I would like to acknowledge the support received throughout this project from both field organizations and the university. Appreciation is extended to: Dan Wilkinson of the Alberta Forest Service for his interest and help in the initial stages of this study; Watershed Section, Alberta Forest Service and Fish and Wildlife, Edson for their continued support throughout the project. Financial assistance was provided by the Forest Development and Research Trust Fund and the National Research Council.

Many thanks are extended to the biogeoclimatic crew at the Northern Forest Research Centre, especially George Krumlik for advice on and assistance with, the ecological aspects of this study.

Sincerest appreciation is extended to my committee, Dave Chanasyk, Kare Hellum and in particular my supervisor, Rich Rothwell, for their patience and constant guidance throughout my program.

In addition, I would like to express special thanks to those friends whose continuous moral support and good humor saw this thesis to completion.

Table of Contents

List of Tables

List of Figures

List of Appendices

I. INTRODUCTION

Land classification has become an increasingly popular forest management tool over the past decade. The form of classification varies with both ecological philosophy and the objectives behind its initiation. In 1976, the Alberta Forest Service began to gather and collate detailed ecological data for the province. The classification used in this on-going project is the biogeoclimatic system devised by Krajina (1970) in British Columbia. Using information so derived, management recommendations will be made for silvicultural and timber harvesting practices.

Biogeoclimatic mapping is based on climatic, geomorphic, soils and vegetation data. All four factors are closely interrelated and affect natural forest development. These same parameters play a key role in determining the hydrologic cycle within a given ecosystem by influencing both the quantity and rate of water movement therein. Therefore, ecological classification may provide a guide to a better understanding of hydrologic processes within a forested watershed.

The major goal of this study is to determine whether local hydrologic interpretations can be made from data collected during biogeoclimatic classification. It was hypothesized that relationships exist between the physical-vegetative features characteristic of the Tri Creeks watershed and the streamflow regimes of its three sub-basins.

II. OBJECTIVES

In order of investigation, the project objectives are as follows:

1. to stratify the Wampus, Deerlick and Eunice Creek sub-basins into units of homogeneous hydrologic response, based on data collected in the process of ecological classification;
2. to investigate unit and basin hydrology through water balance approximations and an index of hydrologic response;
3. to apply the rational formula and regression analyses to peak flow prediction in an attempt to evaluate the hydrologic significance of units delineated.

III. BACKGROUND

A. Land Classification

Many systems have been devised for mapping landscapes, most of which are need-specific. These range from single resource maps, such as the forest cover maps produced by the Alberta Forest Service, to integrated land capability assessments, as in the Canada Land Inventory (McCormack 1965).

The system adopted by the Alberta Forest Service is the biogeoclimatic approach, developed by Krajina (1970). The biogeoclimatic system is based on the premise that vegetation, as well as soil, is a factorial product of climate, soil development, topography, organisms and time (Kojima and Krajina 1975). Primary stratification results in the delineation of areas having distinct regional climate. Within each climatic region vegetative communities are defined so that the species found therein are representative of a unique and manageable site type.

The mapping unit of highest order is the zone. It is characterized by three differentiating features:

1) macroclimate,

2) zonal soil, and,

3) climatic climax plant communities developing on a mesic site.

Zones are then named on the basis of characteristic plant species (Kojima and Krajina 1975). A mesic site can be

defined as, "a naturally occurring, functional ecosystem type which supports zonal (climatic climax) vegetation and soil development, and reflects the regional macroclimate of a zone or subzone" (Green 1978). These broad zones are then subdivided into site specific units based on local hygrotope (moisture gradient) and trophotope (nutrient gradient). Each unit is identifiable in the field by the presence/absence of indicator species.

An example of this can be taken from the most recent biogeoclimatic progress report (Krumlik et al 1979). The Engelmann Spruce - Subalpine Fir zone can be found within Koppen's (McBoyle 1973) microthermal, coniferous forest climatic type. This zone is then divided into lower (1200 - 1400 m a.s.l. to 1550 - 1700 m a.s.l) and upper (1550 - 1700 m a.s.l. to 2200 - 2400 m a.s.l.) elevation subzones. The lower elevation subzone is characterized by Rhododendron albiflorum Hook., Vaccinium membranaceum Dougl., Arnica cordifolia Hook., Arnica latifolia Bong., Rubus pedatus J.E.Smith and a well developed moss layer.

Many of the landscape parameters used in the biogeoclimatic classification exert controlling effects on watershed processes and hydrologic response (runoff expressed as a percentage of incoming precipitation). Their individual importance is dealt with more explicitly in the subsequent section.

B. Basin Morphology

A watershed, or drainage basin, can be defined as an area which is bounded by a topographic divide and drained by a single stream tributary system (Morisawa 1968).

Both the movement and storage of water in a watershed are dependent on many factors. Of specific importance are such variables as; geomorphology, geology, surficial materials, climate, vegetation and land-use (Slaymaker and Lavkulich 1978). These will influence the quantity and timing of flow (Gregory and Walling 1973).

Geology exerts initial control over watershed development. It further influences the type and form of surficial materials which develop through erosion and weathering. These, in turn, will affect the potential for soil moisture storage. The depth at which bedrock is found and the nature of the formation itself will determine the extent of groundwater storage (Gregory and Walling 1973).

Many engineering studies have evaluated the relative importance of selected morphologic basin parameters in terms of their influence on flow quantity and regime. The most significant of these parameters, for a given region, have then been used in the development of flow prediction equations and/or hydrologic models. The most commonly used morphologic measures for comparing basins are: basin order, area, shape, channel length, drainage density, topography, elevation and aspect (Gregory and Walling 1973). These factors appear to account for a significant proportion of

the variation in flow over broad geographic regions and will be discussed briefly in the following paragraphs.

i) Basin Order

Basin order is defined by the stream channel of highest order within a watershed. The ordering of streams involves numerically ranking the main channel and its tributaries. The most commonly used technique is that developed by Strahler (1964). Tributaries at the head of channels are designated as 1st order streams. Where two such tributaries meet, the stream becomes 2nd order and similarly, where two 2nd order streams join the result is a 3rd order stream.

The ordering of streams has proven useful for comparison both within and among basins (Morisawa 1968). Not only does it provide a size-scale index but also indicates the amount of flow which could potentially be produced by a stream system (Gregory and Walling 1973). If all else were to be held constant and given a large enough sample, order number would be directly proportional to watershed size, channel dimensions and stream discharge at that place in the system (Strahler 1964). In broad terms, hydrologic response tends to decrease with increasing basin order (Briere 1978). It should be noted that the ordering of streams is extremely sensitive to the map scale used in its determination.

Strahler (1964) also incorporated stream order into a bifurcation ratio. This he defined as the ratio of the number of streams of a given order (N) to the number of segments of the next highest order (N+1). Generally, this

ratio has been found to range between 3 and 5 for basins in which geologic structures do not exert a controlling influence on channel processes.

ii) Basin Area

The area of a watershed directly influences both total water yield and the timing of flow events. Langbein (1947) has shown that in temperate climates the volume of discharge varies directly with the size of a given basin. Viessman, Knapp and Harbaugh (1977) state that as basin area increases its shape becomes longer and narrower, thus basin geometry is not preserved. This indicates that watershed shape should perhaps be considered in conjunction with area.

iii) Basin Shape

Basin shape, or the distribution of area in relation to distance from the gauging station or outlet greatly affects the time of streamflow concentration. This parameter is strongly influenced by underlying geology.

A circular watershed, in which water from all sources has a comparatively short distance to travel, will produce hydrographs with shorter times to peak and greater flood crests than one in which the greatest proportion of total area is remote from the outlet (ie. oblong in shape) (Langbein 1947).

iv) Channel Length

The length of the main stream channel is largely dependent on basin shape. Exact agreement has been found between valley length and channel length, as might be

expected (Gregory and Walling 1973). When channel length is divided by the mean velocity of flow, the time of concentration is derived (Langbein 1947). This, in combination with drainage density, would provide an indication of comparative response times between basins.

v) Drainage Density

The length of stream channel per unit area is referred to as drainage density. If a basin were uniform in all other regards, then streamflow would be proportional to length of streams in the basin, since channel flow is more rapid than surface flow (Gregory and Walling 1973). Drainage density further affects the efficiency of a drainage system and provides an indication of geologic and surficial conditions.

High drainage densities are generally found where slopes are steep, vegetative cover is sparse, soils are weakly developed and subsurface material is impermeable. Comparatively low drainage densities are associated with highly resistant geologies and/or highly permeable materials under dense vegetation and low relief. Through multiple correlation techniques, Strahler (1964) has shown that drainage density varies directly with the percent of area lacking vegetation and with runoff intensity.

vi) Topography

Both channel slope and side-slope configuration become important considerations when dealing with rates of water yield. Topography exerts its most pronounced effect on flood flows (Langbein 1947) since the steeper the gradient, the

shorter the time of concentration.

The shape of basin side-slopes further affects water distribution and the path of flow taken to the channel. Slopes which tend towards convex cause downslope water movement to diverge. The sharper the curvature, the less runoff and the greater the proportion of water going to deep forms of flow. On straight sideslopes flow is thought to be proportional to the length of slope. Concave slopes are thought to hold the greatest amount of moisture whereas convex slopes would form the drier regimes. The effects of topography on moisture regime are reflected by vegetative composition (Hack and Goodlett 1960). The influence of vegetation on watershed processes will be discussed in the subsequent section.

vii) Elevation

Elevation influences the amount and form of precipitation received in a watershed, ie. the proportion which falls as snow compared to rain.

The area-distribution of elevation influences the distribution of precipitation over a watershed which, if in the form of snow, will be further affected in terms of melt. The area-distribution of elevation is also reflected in watershed slope, which largely determines the potential gradient of flow, again affecting the timing of flow events.

viii) Aspect

The orientation of a watershed becomes a determining factor in both water budget and snowmelt considerations,

this being a direct result of varying amounts of insolation received at different angles to the sun. It has also been found that precipitation varies with aspect, in relation to wind direction (Linsley, Kohler and Paulhus, 1975). Similarly, the processes of evaporation and transpiration would follow parallel trends.

Although predictions of streamflow based solely on morphologic basin parameters have become increasingly reliable over time, it is useful to cite several problems associated with this technique (Linsley, Kohler and Paulhus 1975):

1. The prediction of streamflow through the use of physical landscape features is largely dependent on map quality.
2. Definitions of morphologic descriptors are ofter unclear and may be arbitrary.
3. Relationships between the more static physical environment and highly variable hydrologic parameters are fairly complex and not completely understood.

Despite the vast amount of work done using physical watershed features to predict streamflow, very little has been documented regarding soil moisture distribution under varied vegetation types. Perhaps one of the most detailed investigations of streamflow prediction, based on physiography and general vegetative features, was a study done by Lull and Sopper (1967) in the northeastern United States. Through the use of such independent variables as precipitation, temperature, elevation, slope and percent

forest cover, they attempted to predict annual and seasonal discharges. Table 1 summarizes their results.

From this table it can be seen that flow predictability varies with season. R-squared values for summer versus spring runoff were 0.42 and 0.82 respectively. This would indicate greater variability in undefined summer moisture losses as compared to those occurring in spring. Table 2 illustrates the significance of vegetation, as represented by forest cover, in terms of variability in both annual and seasonal flow. Therefore, the use of vegetation as a predictor, even in the broad sense described here, seems to be supported by Lull and Sopper's analyses.

C. Vegetation

Vegetation is thought of largely as a moderator of such physical processes as: surface runoff, infiltration and erosion. In combination with other environmental factors; species composition, density and distribution (Sopper 1971) influence both inputs to and losses from the hydrologic cycle and thus the amount of water yielded from a basin. The extent of vegetative effects varies with species composition, density and distribution (Sopper 1971).

If plant communities are assumed to be indices of potential runoff, environmental factors important to species presence and growth must be associated with recognizable hydrologic events. Satterlund (1967) hypothesized that, on a local basis, significant relationships between flow and

TABLE 1: Runoff Prediction Regression Analyses (Lull and Sopper 1967)

Multiple Regression Coefficients and Regression and Correlation Statistics

Dependent variables	Multiple regression coefficients for independent variables									Regression and correlation statistics			
	P_A	P_S	P_I	°T	Lat	El	Slp	For	Swp	Intercept	Standard error of estimate	R	R^2
Average annual runoff (in.)	0.6274	—	—	−0.5749	(1)	0.0024	—	0.0619	—	38.06	2.87	0.779	61
Average seasonal runoff (in.)													
Winter	—	0.6485	—	—	−0.3120	0.0013	—	0.0108	(1)	11.74	1.08	0.636	40
Spring	—	0.7616	—	—	1.2657	0.0017	—	0.0380	(1)	−54.91	1.15	0.903	82
Summer	—	0.4611	—	−0.0444	(1)	−0.0007	—	0.0082	(1)	1.18	0.78	0.632	42
Fall	—	0.3751	—	−0.1441	−0.2006	(1)	—	0.0081	—	19.20	0.81	0.584	38

Where: Pa = annual temperature
Ps = seasonal precipitation
T = temperature
Lat = latitude

El = elevation
Slp = slope
For = percent forest cover
Swp = percent swamp

(1) Variable tested but not in final equations.

TABLE 2: F-statistics for Selected Variables Used in Runoff Prediction (Lull and Sopper 1967)

Average Annual and Seasonal Precipitation, Forest Cover, Percentage, and Average Maximum Temperature for July by Physiographic Units, and F-Values

Independent variables	Physiographic units							
	Northern New England	Southern New England	New England Seaboard	Glaciated Plateau	Ridge and Valley	Northern Piedmont	Coastal Plain	*F*-values
Precipitation (in.)								
Annual	39.29	44.54	43.03	39.54	40.24	45.17	43.09	12.90*
Winter	8.30	9.85	7.03	7.79	7.82	9.49	9.32	13.39*
Spring	10.07	11.77	11.23	10.87	11.27	12.14	11.14	10.81*
Summer	10.69	11.84	9.95	11.30	11.58	12.95	12.29	12.15*
Fall	10.21	11.10	11.30	9.59	9.31	10.60	10.33	12.84*
Percentage of forest cover	83	75	73	56	67	34	56	12.26*
Average maximum temperature for July (°F)	81.1	82.9	82.2	81.2	84.8	87.2	85.9	40.35*

* Significant at 1% level.

vegetation should exist. Such trends might be discernible since environmental and genetic variability within species and between geographic regions would be minimized. Some species or associations may be more sensitive than others in their response to water, and/or be more useful indicators in one part of their range than in another. Thus, the use of plant communities, in Satterlund's estimation, would be most appropriate in areas where moisture was a limiting factor in species distribution. Under such conditions, relationships between site and vegetation would become more pronounced. Satterlund (1967) suggested that refinements in the subdivision of forest types through the recognition of subsidiary vegetation or site quality might further enhance the use of vegetation in watershed response prediction. Approaches, such as the biogeoclimatic, developed more recently than Satterlund's discussion, may provide this additional refinement.

D. The Hydrologic Cycle

Reference has been made to the hydrologic cycle throughout the preceeding discussion. This cycle describes the interaction of water with both vegetation and the physical landscape. It represents a continuum involving the motion, recharge and loss of the earth's waters (Gray 1973) and can be divided into three basic phases; precipitation, evaporation and runoff. At some point, each phase may involve temporary storage, a change in state and/or the

transport of water. The nature and magnitude of the various cycle-components is dependent on both physical and vegetative features found within a watershed.

The hydrologic cycle is often expressed in the form of a water balance equation such as:

$$Q = P - ET - I + S$$

where:

Q = runoff,

P = precipitation,

ET= evapotranspiration,

I = interception, and

S= change in soil moisture storage.

This illustrates that the proportion of incoming precipitation reaching the stream channel is a function of several losses upon which the following discussion is based.

Evapotranspiration

Evapotranspiration refers to moisture loss through both evaporation and transpiration. The total volume lost is largely dependent upon radiant energy and to a lesser extent, advective energy. Radiant energy varies throughout a watershed with slope and aspect. Swift (1960) noted a three-fold difference in available radiation between north and south facing slopes at Coweeta, N.C. Advective energy is influenced by stand height and surface roughness which affect the mixing of air and consequently the transfer of

heat (Gray 1973). Evapotranspiration is thought to increase with stand height due to greater utilization of both energy forms and increased turbulence with increasing height of vegetation. Losses caused by both energy sources will also depend on the atmospheric saturation deficit (Zinke 1960).

The rate and amount of evapotranspiration from a site further depends on vegetation type (Table 3) and density, since these factors significantly affect transpiring surface area, net radiation, interception, wind patterns and root distribution (Douglass 1967). If radiant energy is not limiting, then soil moisture becomes the rate-determining factor. This, in turn, is a function of soil texture, soil depth and climate (Anderson, Hoover and Reinhart 1976).

Rooting habits or occupancy of a site, ie. depth and density, will to a large extent determine the opportunity for evapotranspiration losses. Plant roots which occupy the entire soil profile may deplete all available water whereas consumptive use by more shallow rooted species will be limited (Sopper 1971). Rooting characteristics are thought to have their greatest effect on soil moisture losses in climates having distinct wet and dry seasons (Douglass 1967).

Through its influence on the manner in which soil moisture moves from soil pores to plant roots, soil texture also becomes important when considering potential for evapotranspiration. Densely rooted plant species in sandy textured soils may withdraw moisture quickly and therefore

TABLE 3: Mean Annual Potential Evapotranspiration in Selected Forest Types (Anderson, Hoover and Reinhart 1976)

Forest Type	Location	PET (MM)
Slash pine	Lake City, Fla.	1066
Loblolly pine	Athens, Ga.	914
Hardwoods	Jamestown, N.Y.	660
Douglas-fir	Canary, Oreg.	660
Redwood	Eureka, Calif.	635
Red fir	Teakettle, Calif.	635
Ponderosa pine	Williams, Ariz.	584
Spruce-fir	Greenville, Maine	533
Lodgepole pine	Moran, Wyo.	381

evaporation will equal the potential rate until the permanent wilting point is reached. However, in more finely textured soils water movement to the roots may not keep pace with potential loss rates. Consequently, actual evaporative losses will be less than the potential throughout the available water range (Dunne and Leopold 1978).

Evapotranspiration provides the greatest mechanism for change in the quantity of water available for flow, as compared to the other water balance components, since losses via this mechanism often range from 60 - 70 percent of the total precipitation in coniferous forest (Armson 1977).

Interception

For storms of equal intensity and duration, leaves and branches trap varying amounts of the total incoming precipitation depending on species and canopy density (Zinke 1960). That which is subsequently evaporated is termed interception loss. In addition to this loss, precipitation may also be evaporated or sublimated from the forest floor. It has been shown, however, that under full vegetative cover, losses from the forest floor are minor (Armson 1977).

The amount of precipitation intercepted, and thereby available for loss, depends on the density, age and type of vegetation as well as the intensity, amount and form of precipitation (Sopper 1971). Table 4 illustrates the variation in interception losses among forest types (Hewlett and Nutter 1969). It is generally felt that interception has little influence on streamflow. For example, Rothacher

TABLE 4: Median Values of Canopy Interception as a Percentage of Annual or Seasonal Gross Precipitation (Dunne and Leopold 1978).

Forest Type	No. of Obs.	Median Canopy Interception (% of Gross Ppt)
Deciduous forest		
All data	10	13
Coniferous forest		
Rainfall only	11	22
Obs. that include rain and snow	26	28
European data only	9	35
N.American data only	27	27
Taiwan	1	8

(1963) has shown that coastal Douglas-fir forests intercepted only about 4 percent of the precipitation in storms of 20 cm or greater.

Soil Moisture Storage

The amount of moisture which can be stored in a given soil is determined by soil properties such as volume, distribution and size of pores (Armson 1977). Soil water is held through either retention or detention storage (Anderson, Hoover and Reinhart 1976). Retention storage is a result of soil matric forces at moisture contents generally below field capacity. Field capacity is defined as the soil moisture content at 1/3 bar suction. Detention storage is water held temporarily in large soil pores, before moving towards groundwater or the stream channel, under the force of gravity (Armson 1977). In coarse textured soils, retention storage is low, compared to detention storage, while the reverse occurs in finer textured soils. Both types of storage will vary with soil depth, texture, coarse fragment content and organic matter.

Surface water holding capacity is influenced by the type of forest floor, which includes both humus and litter (Armson 1977). Golding and Stanton (1972), however, did not observe any real difference in water holding capacity under lodgepole pine or spruce-fir forests. Both had capacities of 0.18 - 0.19 cm of water per cm of forest floor thickness.

Theoretically, maximum soil-water storage in a soil is the difference between field capacity and permanent wilting

point (15 bar) moisture content over the entire profile. This is also referred to as available water for plant use. Rapid soil water movement occurs at moisture contents of field capacity and greater. Soil-water storage potential varies with texture. In general, for soils of equal depth, the finer textured the soil, the greater will be the storage capacity. Further, the deeper the soil the greater the water storage potential, provided similar bedrock conditions exist.

E. Variable Source Area Concept

In the foregoing discussion, it has been shown that components of the water balance vary with many of the same factors used in the separation of site types such as, local climate, vegetative association and soil properties. The manner in which individual sites contribute to total flow further varies with position in the watershed.

It is generally agreed, among forest hydrologists, that only a small portion of a watershed contributes directly to stormflow. The relatively small area that does produce storm runoff expands and contracts in response to rainfall intensity, antecedent moisture conditions and soil conductivity. Between storms, flow is sustained to a large extent from unsaturated, downslope water movement. Theoretically, such water movement would create a gradient of increasing soil moisture in the downslope direction. Saturated areas bordering the main stream and ephemeral

channels would thus be primed for rapid release of water during storm events, (Helvey, Hewlett and Douglass 1972). This is known as the variable source area concept and is described in detail by Dunne and Black (1970).

That portion of a watershed contributing to stormflow has been found to vary from 1 to 50 percent of the total basin area, depending on the size of storm (Hewlett and Nutter 1969). This variation is due to both slope water movement and channel expansion. Kirkby (1978) suggests that it is the lower 25 percent of a given slope which undergoes the smallest seasonal change in moisture content and concludes that it is this zone which controls moisture contributions to streamflow.

Since soil moisture is an important factor in the establishment of vegetative communities, it is hypothesized that using biogeoclimatic data, units corresponding directly to contributing areas defined by variable source theory may be delineated. It is on this premise that further attempts to relate the classification scheme to hydrologic response will be based.

Further, once these contributing areas have been defined, flow from zone(s) at or near saturation could be assumed the major contributor to storm or peak runoff. The contributing area could then be used for flow calculations based on the rational formula (Chow 1964). Theoretically, estimates of peakflow through application of the rational method should approach the actual values obtained at the

gauging stations if saturated zone delineation approximates the contributing area described by variable source theory.

F. The Rational Formula

The rational formula was originally developed to estimate flow from small watersheds having an area of less than 13 sq km (Chow 1964). It is based on the premise that for storms of uniform intensity and distribution over a basin and of unlimited duration, the entire basin will contribute to stormflow at the outlet. This being the case, maximum runoff per unit area occurs at the time of concentration and, storm duration is equal to the time of concentration. Thereafter, flow remains constant until precipitation ceases. Also, the volume of water held in storage equals the volume under the hydrograph recession limb (Gay 1973).

It has been suggested (Gay 1973) that although rational theory evaluates lag effects due to travel time, it does not account for storage or rapidity of flow in channels. This becomes important in watersheds characterized by flat topography and poorly defined stream channels.

The actual formula is as follows:

$$Q = ciA$$

where:

Q = peak discharge (cfs)

c = runoff coefficient

i = rainfall intensity (in/hr)

A = area (acres)

The runoff coefficient varies with topography, soils and vegetative cover. Further, high intensity storms, which occur less frequently, require the use of larger coefficient values since factors affecting the proportion of precipitation resulting in runoff, such as infiltration, have a smaller effect on peak flow (Chow 1964).

The assumptions involved in the solution of the rational formula have been summarized by Chow (1964):

1. The rate of runoff for a storm of given intensity is maximized when storm duration equals or exceeds the time of concentration.
2. A linear relationship exists between peak flow and storm intensity implying that flow equals zero when intensity equals zero.
3. The frequency of peak flow events equals that of the given rainfall intensity for a given time of concentration.
4. The relationship between peak flow and watershed size equals that between storm duration and intensity.
5. The runoff coefficient is constant for all storms, regardless of frequency, in a given watershed.

The literature suggests that the above assumptions may be reasonable for such problems as urban storm sewer and paved lot design, if they are of fixed dimensions and

hydraulic characteristics. Since the assumptions are highly suspect for other situations, caution is urged in formula application. Due to its simple nature, however, it is frequently used as an approximate estimator of flow from small basins.

IV. THE STUDY AREA

The area selected for this study was the Tri Creeks experimental watershed located roughly 40 km southeast of Hinton, Alberta. This has been an area of intensive study by both the Alberta Forest Service and, Fish and Wildlife since 1967. Therefore, a considerable amount of data is readily available for interpretation. Tri Creeks consists of three sub-basins; Wampus, Deerlick and Eunice Creeks, which together occupy an area of 59 square km. All three creeks flow northward into the McLeod River (Fig. 1).

A. Land Use

Historically, the major land-use in the area has been logging. Both select and clearcut logging were carried out in the lower portion of all three basins in the 1950's. Extensive geophysical exploration occurred during this period and two gas wells were eventually drilled.

In 1965, the area was set aside as an experimental watershed to determine the effects of harvesting on aquatic life, streamflow and water quality. In 1977, following ten years of pre-treatment data collection, St. Regis (Alberta) Ltd. began removing timber in the Wampus Creek basin according to Alberta Forest Service Groundrules. Once completed, further harvesting will be carried out in the Deerlick Creek basin, again in the form of alternate blocks, however, no streamside buffers will be retained. Eunice Creek will remain the control basin. In total, 50 percent of

FIG 1 TOPOGRAPHIC MAP OF TRI CREEKS, ALTA

Scale 1 cm = 100 m

Contour Interval 30 m

the merchantable timber is to be removed from both Wampus and Deerlick Creeks.

All three basins have been gauged for both climatological and streamflow data, as well as water quality since 1967.

B. Climate

Based on Koppen's system of classification, the climate at Tri Creeks is humid, microthermal and subarctic. The mean annual precipitation is 688 mm of which 38 percent falls as snow. Winters are generally cold and summers, cool and short with only two to three months having mean daily temperatures above 10°C (Jablonski, 1978). Periodically, chinook winds occur in the area leading to "red-belting" in the upper end of the Tri Creeks basin. The mean annual temperature is -0.7 °C.

C. Geology and Geomorphology

General basin morphology, as summarized by Currie (1969), is given in Table 5. The Tri Creeks area consists of extremely folded and fractured bedrock of predominantly sandstones and shale, with fold and thrust planes running in a southwesterly direction (Currie 1969). Bifurcation ratios cited in Table 5 show little geologic control over flow processes in both the Eunice and Deerlick basins. However, the ratio of 5.6 cited for Wampus Creek indicates strong geologic control. This is explained in part, by the strike

TABLE 5: Morphologic Data for Tri Creeks, Alta. (Currie 1969)

Basin	Area sq-km	Stream Order	No. of Streams	Bifurcation Ratio(1)	Total Length (km)	Stream Freq.(2)	Drainage Density(3)	Relief Ratio(4)
Wampus	27.5	1	93	3.30	41.6			
		2	28	5.60	21.8			
		3	5	5.00	5.4			
		4	1		5.3			
Total			127		74.1	12.3	4.5	0.04
Deerlick	13.7	1	49	4.90	15.0			
		2	10	5.00	4.6			
		3	2	2.00	4.2			
		4	1		6.6			
Total			62		30.4	10.7	3.3	0.05
Eunice	15.9	1	50	4.55	24.8			
		2	11	3.67	12.8			
		3	3	3.00	3.7			
		4	1		6.5			
Total			65		47.8	9.8	4.7	0.06

(1) number of streams of one order divided by the number of streams of the next highest order

(2) total number of streams divided by basin area

(3) total length of streams divided by basin area

(4) drainage density divided by stream frequency

valley through which the upper reaches of Wampus Creek flow.

The northern third of Tri Creeks is covered by glaciolacustrine silts which overlie loam to clayloam textured Marlboro till. The remainder of the basin consists of local till. This is thought to have been transported only a short distance since it contains many soft sandstone fragments. It is non-calcareous and sandy-loam in texture. Other minor deposits are alluvial in nature and occur along channel banks. Generally, these deposits have distinct, elevational extents: the glaciolacustrine ending at roughly 1380 metres; local till over bedrock occurring from 1380 to 1440 metres; and, above 1440 metres the bedrock is either exposed or lying at less than 1.5 metres beneath the surface (Currie 1969).

Groundwater movement in the Tri Creeks area follows bedding planes and joints in the bedrock. Flow in the surficial materials is largely governed by their permeabilities. Currie (1969) found the depth of active groundwater flow to be less than 91 meters and that residence time below the surface was short. This would indicate that streamflow response to changes in groundwater levels would be rapid in most portions of the basin.

D. Soils

Two main soil associations have been described in the Tri Creeks area (Dumanski <u>et al.</u> 1972). The Robb association, which covers most of the basin, consists of

moderately to very stony tills. Soils in this association are primarily Brunisols and Luvisols. The Tri Creeks soil association occurs along lower slopes and consists of heterogeneous lacustrine materials containing isolated coarse fragments. These soils are generally found adjacent to major drainage channels and extend from the channel to the nearest topographic rise. They do not, however, occur above 1380 metres. The Tri Creeks soils are classified as Luvisolic.

Two minor soil complexes are also described. The Erith complex, located intermediate between the well drained uplands and organic depressions, consists of Gleysolic and Organic soils. The second minor soil complex, is the Alluvium complex, which occurs along lower Wampus Creek and consists of Brunisols and Regosols.

E. Vegetation

Forest cover extends to the ridgetops throughout the Tri Creeks area, except for several of the uppermost knolls. Major tree species are; _Pinus contorta var. latifolia_ Dougl. (lodgepole pine), _Abies lasiocarpa_ (Hook.) Nutt. (alpine fir), _Picea mariana_ (Mill.) B.S.P. (black spruce), _Picea glauca_ (Moench) Voss (white spruce) and _Picea glauca x engelmannii_ (Engelman-white spruce hybrid). Lodgepole pine occurs as an early successional species and is predominant towards the headwaters due to recent fire. Black spruce is the major species in the valley bottoms. Mature stands

consist of spruce-fir associations, which vary with aspect and elevation throughout the basin. Vegetative types, including lesser vegetation, will be described in more detail in the results section of this thesis.

F. HYDROLOGY

Since 1967, continuous summer discharge values have been recorded at the outlet of Wampus, Deerlick and Eunice Creeks. Total monthly values are given below and seasonal hydrographs for each creek in Figure 2.

TABLE 6: Total Monthly and Seasonal Discharge (area-mm) (1967-1977)

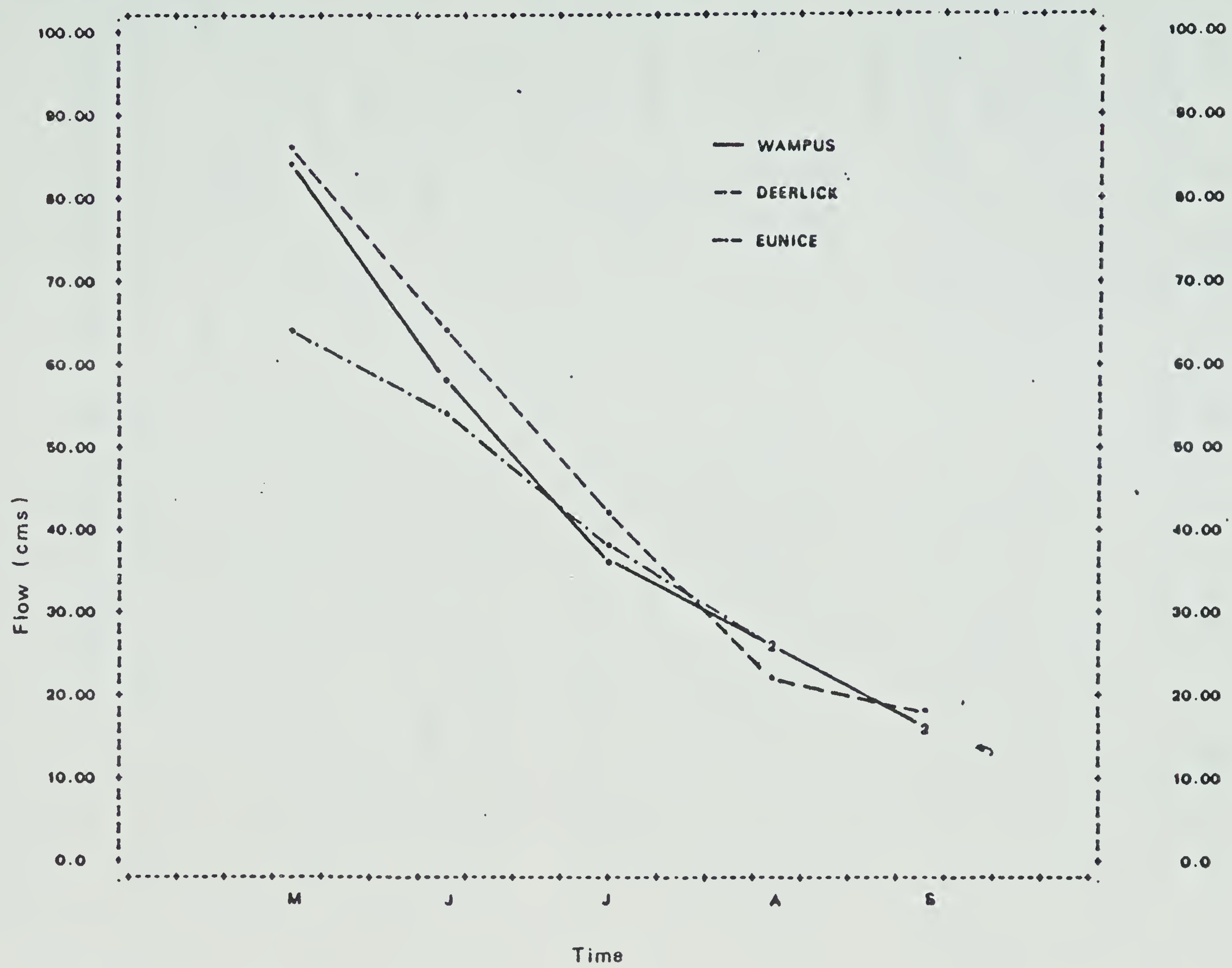
Month	Wampus	Deerlick	Eunice
May	83.06	85.60	63.75
June	57.66	64.77	53.34
July	35.05	41.40	38.61
August	25.40	21.34	25.65
September	15.74	17.53	16.00
Total	216.91	230.64	197.35

Maximum discharge, ranging from 83 area-mm from Wampus to 64 area-mm from Eunice, occurs in late April as a result of spring snowmelt. Snowmelt contribution to runoff is described in subsequent discussion and averages annually 84

FIG 2 HYDROGRAPHS FOR TRI CREEKS, ALTA.

SUMMER STREAMFLOW

SCATTERGRAM OF (DOWN) FLOW (ACROSS) MONTH



mm of water equivalent. Trends in early summer runoff from both Wampus and Deerlick basins are (83 and 86 area-mm respectively) while flow from Eunice Creek is less (64 area-mm). Flow over the remaining season is comparable for all three basins. Total seasonal discharge is greater for Wampus and Deerlick Creeks (217 and 231 area-mm respectively) as a result of reduced runoff shown in Eunice during May. The similarity in flow volumes per unit-area of all three basins allows relative ease in comparison of their hydrologies.

The hydrographs for each basin illustrate the variation in total runoff with area. Wampus Creek, having the greatest area, 27.5 sq km, also has the greatest flow, both monthly and seasonal. Deerlick and Eunice Creeks are similar in extent (13.7 and 15.9 sq km) and exhibit comparable flows of roughly 36 cms over the season.

Times of concentration, are also related directly to basin morphology. In this case the determining factors are basin length and slope. As shown in Table 7, Wampus Creek has the greatest time of concentration (132 mins) as well as the greatest main channel length (15,642 m) and slope (three percent). Eunice Creek has the smallest time of concentration (72 mins), a main channel length of 8,910 m and average slope of four and a half percent.

TABLE 7: Time of Concentration for Tri Creeks, Alta.

	Elev. (m)		Main Channel Length(m)	Slope	Tc (min)
	Max.	Min.			
Wampus	1690	1249	15,642	0.028	132.2
Deerlick	1663	1253	9,999	0.041	81.1
Eunice	1663	1261	8,910	0.045	71.5

V. METHODOLOGY

A. Preliminary Studies

Prior to actual commencement of this study an analysis of streamflow prediction, based on morphologic basin parameters, was attempted for the Tri Creeks area. This was done in order to determine the potential use of such variables, in hydrologic analyses and, to compare such techniques with refinements suggested in this thesis. Stepwise, linear regressions were run using the Statistical Package for the Social Sciences (Nie 1975). Two sets of regressions were examined for each of the five summer months (May to Sept.) over a period of four years. The number of cases examined equalled 44.

In the first of these, total flow from each of the three basins was regressed on: precipitation, basin order, area, aspect, maximum elevation, slope, main channel length, drainage density and percent of total area forested. A second run was made holding area constant, that is, the dependent variable was flow per unit-area. The independent variables remained the same. Those variables which appeared to explain only a minor portion of flow variability were eliminated in each run and the remaining significant predictors were considered for discussion.

B. Stage 1 - Ecology

Field Sampling

Ecological data for the stratification of Tri Creeks, was collected in the summer of 1979. This constituted a major portion of work done in the field.

Fifty ecological plots were established throughout Tri Creeks, over a three month period. The intensity of sampling used exceeded that which normally would be applied in the general biogeoclimatic classification scheme. However, a greater degree of sampling is commonly used for specific interpretations. Initially, transects were located roughly 1.6 km. apart, on alternating aspects, along each of the three major stream channels. Plots were then established at upper, mid and lower slope positions. Each plot covered an area of 200 square meters. This general scheme was modified in the field according to access. The actual locations are shown in Fig. 3.

Once a plot was established data were recorded on standard biogeoclimatic forms (see Appendix 1). Included in the survey were: a general physiographic description; percent of plot occupied by vegetative strata, as well as other ground cover including decaying wood, water, rocks etc.; a brief stand description; a complete list of vegetative species according to strata, noting percent cover and vigor; and, a soil profile description (Canadian System of Soil Classification 1978). Soil samples were taken from all horizons, greater than 2.5 cm thick, at each soil pit.

FIG 3 TRI CREEKS, ALTA

-PLOT LOCATIONS

Bulk density samples were obtained at plots along two previously established transects, located across the upper and lower end of the three sub-basins, using a bulk density sampler. Two cores were taken from 18 profiles, one in the upper B and the second in the upper C horizon. On the average, the centre of the core was located at 15 and 30 cm below the ground surface. These cores were immediately wrapped in plastic and later shipped to the laboratory.

Soil Analyses

One week after sampling, 1/3 and 15 bar (through use of pressure membrane and plate apparatus) moisture contents were determined in the laboratory, as well as bulk density and porosity (Black 1965). Available water was defined as the difference between 1/3 and 15 bar moisture contents of the soil cores.

Data Analyses

The vegetative data were coded on the basis of species presence/absence and later according to cover class (see Table 8). Dissimilarity analyses were carried out using the Cluster Analysis package (Wishart 1978), to determine whether distinct groupings of vegetation exist within the Tri Creeks area. The resultant groups were considered in relation to actual field observations to avoid spurious results. Once vegetative clusters or groups were established, a phytosociological table was produced. Basically, this is a listing of cover found to be indicative of each group defined, as well as those species which are

TABLE 8: Cover-Abundance Scale

Cover Class	Abundance(%)
9	>75
8	51-75
7	34-50
6	26-33
5	11-25
4	6-10
3	2-5
2	<1
0	absent

ubiquitous.

Upon examining percent coverage of several species in the ubiquitous category, it became apparent that merely the presence of an individual species in one of the groups would sway its designation, as unique or ubiquitous, to one or both of the groups. Frequency distributions were then plotted for these species to determine which group they were most indicative of.

The soils data were stratified according to parent material type (lacustrine versus till) and tested for potential differences using a t-test.

By combining the results of both the vegetation and soil analyses, through a series of map overlays, and the findings of variable source area investigations by other authors, the Tri Creeks watershed was then separated into homogeneous hydrologic units. Two units were identified:

1. a saturated zone located in the valley bottoms bordering stream channels and;
2. an unsaturated zone which covered the remaining watershed slopes.

C. Stage 2 - Hydrology

For each of the hydrologic units proposed, simple water balances were calculated. The following paragraphs briefly outline the methodology used to derive each of the required parameters.

Precipitation

Weekly summer rainfall data have been collected, using standard rain gauges, at 15 sites in Tri Creeks, since 1974. These data were summed, for each station, to derive total monthly values for each year. The monthly data were averaged over the sample period (1974-78) and added to obtain total seasonal rainfall.

The values obtained were then used to plot an isohyet map of the watershed. This map provided the base for calculating the rainfall received per unit area in each hydrologic unit.

Evapotranspiration

Since energy from the sun provides the driving force for evaporative processes, most authors have used solar radiation as the basis for an energy balance approach to evapotranspiration calculations (Cheng 1968). The energy balances used in this thesis are described below.

For daylight hours, net radiation can be calculated as follows:

$$Qn = Qs - aQs - Qlw + Qv$$

where:

Qn = net radiation

Qs = short-wave radiation

a = albedo

Qlw = long-wave radiation

Qv = advected energy (assumed to be negligible)

At night, net radiation is assumed to equal long-wave radiation loss (Dunne and Leopold 1978). Cheng (1968) expressed long-wave radiation as:

$$Qlw = cT^4(0.56 - 0.08\sqrt{e})(1 - AC)$$

where:

c = Stephan Boltzmann constant(1.17×10^{-7} cal/cm^2/°K /day)

T = air temperature (°K)

e = vapor pressure of the air (mb)

A = constant depending on cloud type

C = cloudiness (decimal fraction of sky covered)

The error associated with this method has been estimated as within 25 percent depending on the uniformity of cloud conditions.

Evaporation was then evaluated by the following equations (Dunne and Leopold 1978):

Daylight:

$$E = Qs - aQs - Qlw/\ pL(1+R)$$

Night:

$$E = Qlw/\ pL(1+R)$$

where:

p = density of water

L = latent heat of vaporization

R = Bowen's ratio

Bowen's ratio expresses the partitioning of thermal energy into sensible and latent heat (Gay 1972).

$$R = 0.00061P((Ts-Ta)/(es-ea))$$

where:

P = atmospheric pressure (mb)

Ts = surface temperature of water (°C)

Ta = air temperature (°C)

es = saturation vapour pressure (mb)

ea = actual vapour pressure (mb)

For the purposes of this study, the following assumptions were made in order to solve the given equations:

1. Qs was estimated from values given in Buffo, Fritschen and Murphy (1972).
2. The albedo of the saturated zone was assumed comparable to that of a black spruce bog, roughly 7 percent (Berglund and Mace 1966). Reflectivities for spruce and pine forests of 15 and 11 percent respectively were used (Dunne and Leopold 1976).
3. Both Ts and es represent the evaporative surface. The temperature difference between the canopy and atmosphere in a pine forest was assumed approximately 0.03 °C and, 0.22 °C in a spruce-fir forest (Jarvis, James and Landsberg 1976; Gay 1972).

4. Cloudiness and type of cloud cover could be considered as a constant over the study area, during the 10 years of data collection, for the summer season in total. This, therefore, could be omitted from long-wave radiation calculations.
5. Once evaporation has been evaluated, evapotranspiration was calculated as 80 percent of the total loss based on estimates by Penman (Bruce and Clark 1966) for summer months.

Based on values calculated at each of three points, the Theissen polygon method of apportionment was used, to obtain total evapotranspiration from each unit type over the Tri Creeks area.

<u>Interception</u>

Based on the literature, interception loss was assumed to equal 27 percent of the total incoming precipitation (Dunne and Leopold).

<u>Soil Moisture Storage</u>

The valley bottom areas were assumed to be at or near saturation for the entire season. Therefore, any change in storage within this unit would be negligible.

Hillslope soil moisture conditions were assumed to be at saturation in May due to snowmelt beginning in late March and continuing till early May. This initial moisture was then assumed to be depleted, over the summer months, to the field moisture content measured in early September. The differences between the saturation and field moisture

contents were converted to volumetric values assuming that the bulk densities of and depth of material in which the field samples were collected approximated the area available for storage. The sample obtained at greatest depth was taken at the upper boundary of the C horizon. It was assumed that any water percolating beyond this interface would contribute a negligible amount of flow to the stream channel. The volumetric difference in storage over the season was used as the soil moisture contribution to flow from the unsaturated zone.

Snowmelt

Eleven snow courses were established in Tri Creeks in 1968 of which eight were located in undisturbed forest. These eight were used as sample points for snowmelt estimation. April water equivalent values were averaged over the sampling period, and taken to be the snowmelt contribution to flow at each sample point. This was based on the previous assumption of initially saturated soil moisture conditions in late March. Consequently, any melt occurring in April would be excess.

Since there were no discernible differences in mean water equivalents between sample points, values from all stations were averaged to obtain an approximate snowmelt contribution for the entire watershed.

D. Water Balances and Hydrologic Response

Using the various parameters determined independently, estimates of total runoff from Wampus, Deerlick and Eunice Creek basins were made by the water balance approach. This estimated value was then compared to the actual flow measured at the outlet of each basin.

The estimated inputs and losses, once ascertained as being realistic through the above comparison, were used to estimate runoff from the identified hydrologic units on a unit-area basis. These estimated values were then summed to obtain an area-weighted estimate of total runoff for each basin. These totals were once again compared to the gauged flow for all three creeks.

The relative contribution of each unit to overall runoff was calculated using the estimated values. Further calculated was an index of hydrologic response for each unit type and each of the three basins as a whole. Hydrologic response, as used here, is runoff expressed as a percentage of incoming precipitation.

The results of the above procedures will be described in relation to the general hydrology of the Tri Creeks watershed.

E. Stormflow Prediction

Though the use of the rational formula is not suitable for the evaluation of absolute magnitudes of flow or that from non-contributing areas in terms of stormflow, it was

hypothesized that rational theory would provide insight into the relative runoff produced by the contributing area. It would also give some indication as to the relative extent of the saturated zone.

Stormflow was predicted using the rational formula, for both spring (May - June) and summer (July - Sept.) storms in the Tri Creeks area. The runoff coefficient used in the rational formula was set equal to one since it was assumed that for the area contributing to stormflow, the ratio between a unit of added precipitation and resultant runoff equalled unity. All precipitation, rainfall intensity and stormflow data were obtained from the Alberta Forest Service, Watershed Section, data tabulations. All storms considered, involved total precipitation greater than 25 mm. Further, whenever possible, isolated storms were selected to avoid the confounding effects of antecedent precipitation.

Once peak flows had been estimated, these values were compared to the actual flow measurements obtained at the gauging stations for 30 storms. Similarly, actual flow values were used to calculate the contributing area which would be required by the formula to obtain that flow. Again, these area values were compared to those based on vegetative associations.

A series of stepwise, multiple regressions (Nie 1975) were conducted to evaluate the predictability of peak flows based on the mapped contributing area and precipitation parameters (including: antecendent precipitation, defined as

the volume received in the preceeding storm and later distributed over the time lag between the two storms; storm intensity; duration; and, time of season).

VI. RESULTS AND DISCUSSION

A. Regression Analyses of Morphologic Parameters

Results of stepwise regression analyses conducted on several morphologic basin parameters at Tri Creeks are presented in Table 9.

For total flow prediction, it was determined that precipitation, maximum elevation and area explained the greatest proportion of variability. Variables such as basin order, aspect, slope, channel length, drainage density and area forested were not useful predictors at Tri Creeks. This could be due to the physical similarity between basisns. The three parameters used in prediction, however, accounted for only 30 percent of the total variability in flow. This, therefore, did not provide an acceptable predictor of flow as noted by the R-square value of 0.36.

On a unit-area basis, precipitation and maximum elevation appeared to be the significant independent variables. Still, these only accounted for 40 percent of variability in flow, again not particularly acceptable as a flow predictor.

It was concluded that morphologic basin parameters alone do not provide an adequate means of describing basin flow from such small watersheds as those at Tri Creeks. It is suggested that the higher predictability cited by Lull and Sopper (1967) was due to the greater degree of variability among the basins examined ie. over the

TABLE 9: Regression Analysis for Tri Creeks, Alta.

Dependent variable = Total Streamflow

Elev	A	Ppt	MULTIPLE R	R-SQUARE	R-SQ. CHANGE	SIMPLE R
		x	0.46248	0.21389	0.21389	0.46248
	x	x	0.53887	0.29038	0.07649	0.20339
x	x	x	0.59819	0.35784	0.06746	0.36650

Dependent variable = Flow per unit-area

Elev	Ppt	MULTIPLE R	R-SQUARE	R-SQ. CHANGE	SIMPLE R
	x	0.55924	0.31275	0.31275	0.55924
x	x	0.62905	0.39571	0.08206	0.48791

northeastern United States. On a local basis, such as at Tri Creeks, vegetative associations may be indicative of qualitative hydrologic characteristics not readily discernible from simple basin morphology. When used in conjunction with physical parameters, vegetative characteristics should then improve the predictability of flow.

B. Basin Stratification

The stratification of the Tri Creeks watershed into hydrologic units was initially based on the clustering of plots having similar percent areal coverage of plant species and led to the separation of two vegetative groups (see Appendix 2). The first of these, Unit A, contained vegetative associations characteristic of wet, valley bottom areas and saturated meadows surrounding ephemeral channels and springs. Based on this grouping, the phytosociological table (see Appendix 3) and frequency distributions (see Appendix 4), several species could be cited as indicative of Unit A. These include members of the genera _Carex, Geum, Salix and Betula_ species. Percent areal cover of all species indicated may be found in Appendix 3.

The second group of plots (Unit B) contained vegetation characteristic of drier upper slopes in the watershed. Predominant species in Unit B were; _Arnica cordifolia_ Hook., _Cornus canadensis_ L., _Ledum groenlandicum_ Oeder and several _Vaccinium_ species. Further, Unit B contained the majority of

tree species. Some overlap did exist in terms of both herbaceous vegetation and timber type. _Picea mariana_ (Mill.)B.S.P., for example, occurred in Unit A, as well as in a mix with other species at the lower extent of Unit B.

The forms of vegetation found in each unit or group of plots (ie. the more open meadow types indicative of A as compared to the closed canopy forest types characteristic of B) allowed for considerable ease in the mapping of these zones using 1:15,840, black and white, areal photography obtained from St. Regis, Alberta Ltd.

Data resulting from the laboratory analyses of soil cores collected in the field are shown in Table 10. Upon examining these data, no significant differences were found between the soil properties determined for each of the two parent material types found at Tri Creeks. Soil moisture storage capacity values, as estimated on the basis of soil core data for the depth sampled, are given in Table 11. T-statistics for comparisons of available soil moisture storage capacity between lacustrine and glacial till parent material types are presented in Table 12. The lack of variability noted in the above paramters, over the entire Tri Creeks area, could largely be a function of the proximity of sample location distribution (within 59 sq km) and the homogeneity of geology from which parent materials originated (Currie 1969). This homogeneity in parent material textures would then be reflected in similar water retention capabilities over the three basins, influencing

TABLE 10: Soil Core Analyses for Tri Creeks, Alta.

Plot #	Depth cm	BD g/cc	P %	Field MC%	1/3 Bar MC%	15 Bar MC%	AW %
20	15.2	1.08	55	40	30	14	16
20	15.2	1.00	59	51	33	14	19
21	10.1	1.27	50	32	24	9	15
21	15.2	1.58	23	25	41	9	16
22	12.7	1.12	40	27	58	6	21
22	12.7	1.50	26	26	42	10	16
23	15.2	0.96	33	32	57	13	19
23	15.2	1.42	22	26	45	11	15
17	15.2	1.16	49	35	56	15	20
16	10.1	1.07	48	34	58	11	23
16	12.7	1.84	19	23	38	8	15
18	15.2	1.38	31	25	48	8	17
18	15.2	1.69	21	22	39	6	16
19	15.2	1.26	42	31	54	13	18
19	15.2	1.44	30	16	42	8	8
24	15.2	1.04	22	23	58	14	9
24	15.2	1.38	20	22	48	10	12
48	15.2	1.02	17	22	60	9	13
48	15.2	1.39	13	16	48	8	8
25	12.7	1.32	33	28	47	6	22
25	12.7	1.09	34	26	57	13	13
14	10.1	1.42	28	26	45	7	19
14	12.7	1.48	27	26	42	14	12
15	15.2	0.89	47	36	59	13	23
15	15.2	1.56	24	24	40	11	13
10	15.2	1.27	32	33	52	10	23
10	15.2	1.48	27	32	46	14	18
30	10.1	1.01	24	30	62	11	19
30	12.7	1.37	18	18	49	23	17
11	15.2	1.33	27	26	48	9	17
11	15.2	1.63	22	31	37	11	20
38	15.2	1.04	63	26	65	11	15
38	15.2	0.81	41	29	64	10	19
31	15.2	1.43	31	31	45	32	21
31	15.2	0.91	71	33	64	16	17

Moisture contents expressed as mass.

TABLE 11: Estimated Soil Moisture Storage Capacities

Parent Material Type	Storage Capacity (cc)
Glacial Till	6.04
	3.95
	3.71
	5.49
	5.00
	6.21
	8.51
	8.42
	4.86
Lacustrine	5.53
	5.79
	6.03
	6.34
	6.01
	7.70
	5.22
	4.73
	6.94

TABLE 12: T-statistics for Storage Analyses

VARIABLE	NUMBER OF CASES	MEAN	STANDARD DEVIATION	STANDARD ERROR	T VALUE	DEGREES OF FREEDOM	2-TAIL PROB.
Glacial Till	9	5.7989	1.726	0.575			
					-0.36	16	0.723
Lacustrine	9	6.0322	0.892	0.297			

rates of water movement and amounts stored.

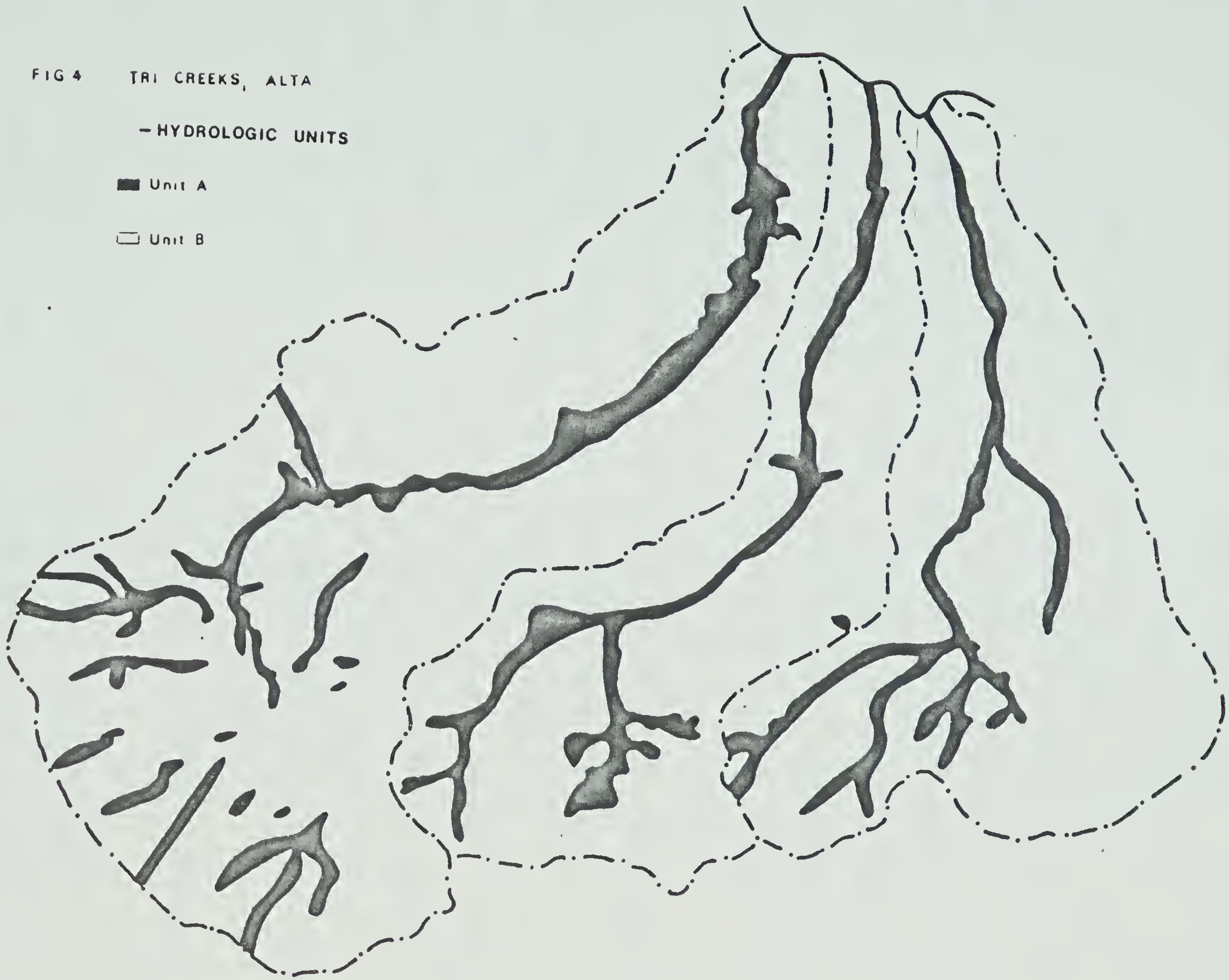
It should be noted, however, that only thirty-six soil cores were collected, at 18 plots, over the entire 59 sq km. This does not provide a sample size of sufficient magnitude to allow conclusive statements regarding soil water retention. It does, however, provide an indication of homogeneity in the soil characteristics along slope segments sampled. The homogeneity illustrated by the analyses also appears to correspond to the lack of variability observed in vegetative associations along the watershed slopes. Since it can be assumed that vegetation reflects local moisture regimes (Satterlund 1967), the findings discussed above were taken as sufficient for basin stratification.

The three basins; Wampus, Deerlick and Eunice, were stratified into two hydrologic units; their delineation being derived solely from the vegetation analyses (Fig. 4).

For the time periods dealt with in this study then, Unit A was assumed to be an area characterized by continuous, saturated or near-saturated flow. Unit B, on the other hand, was assumed to have a soil moisture content at or near saturation only during spring snowmelt. Unsaturated flow was be assumed to be the predominant flow mechanism for the remainder of the season in Unit B.

FIG 4 TRI CREEKS, ALTA

–HYDROLOGIC UNITS



C. Initial Water Balances

Runoff from each of the three Tri Creeks basins was calculated by the water balance approach described earlier. Both inputs to and losses from each basin were calculated prior to stratification and are shown in Table 13. Runoff values (Qest) were estimated and compared to the actual values measured at the outlet. The results of this comparison indicate that the water balance approach and the manner in which its various components were derived provided a good estimate of actual flow. Streamflows from Wampus and Deerlick were estimated within one and three percent of the actual, respectively. Total seasonal flow for Eunice was overestimated by roughly 25 percent.

The overestimation resulting for Eunice Creek suggests that additional losses may occur in this basin which do not exist in Deerlick and Wampus. Since the geology and soils of each basin are similar it is assumed that added storage potential does not exist in Eunice. It has been suggested that geologic strata in the Tri Creeks area dip in a southwesterly direction (Currie 1969). Should these strata and the region of subsurface flow overlap in a portion, or portions, of the Eunice basin, then leakage could be expected out of the basin.

An alternate explanation might be that insufficient channel control occurs at the Eunice gauging station. This would lead to flow, either surficially or at depth, remote from the actual streamflow gauge. Such a condition would

TABLE 13: Water Balances for Tri Creeks, Alta. (area-mm)

Basin	Qactual	Ppt	Et	I	S	SM	Qest.	Estimate Deviation from Actual
Wampus	217	377	171.5	101.8	26.8	84.6	215	-1%
Deerlick	231	379	165.0	102.3	27.1	84.6	224	-3%
Eunice	197	396	158.8	107.0	26.9	84.6	247	25%

again lead to an unaccounted-for loss and thus the overestimation by the water balance method.

The larger flows calculated for Eunice may also be a result of an overestimate of precipitation. Incoming precipitation, as shown distributed over the Tri Creeks area in Fig. 5, is heavily weighted towards the higher values in Eunice. This is a result of the lack of data available for upper Eunice.

The deviation in estimated from actual flow being 25 percent, however, still implied that use of the established technique was suitable for the evaluation of basin hydrology. This is a reasonable assumption since the methods used for calculating evapotranspiration are only reported as being accurate to within 25 percent (Dunne and Leopold 1976). The error inherent in the calculation of losses from the system may, therefore, approach or exceed the 25 percent deviation.

D. Water Balances for Hydrologic Units

Areas occupied, within each basin, by the two hydrologic units are given in Table 14. The various water balance components were then apportioned over each of these areas.

Precipitation was distributed over the Tri Creeks area by the isohyetal method as shown in Figure 5. Using values, obtained by this method, total rainfall for each unit is

FIG 5 TRI CREEKS, ALTA

– PRECIPITATION (mm)

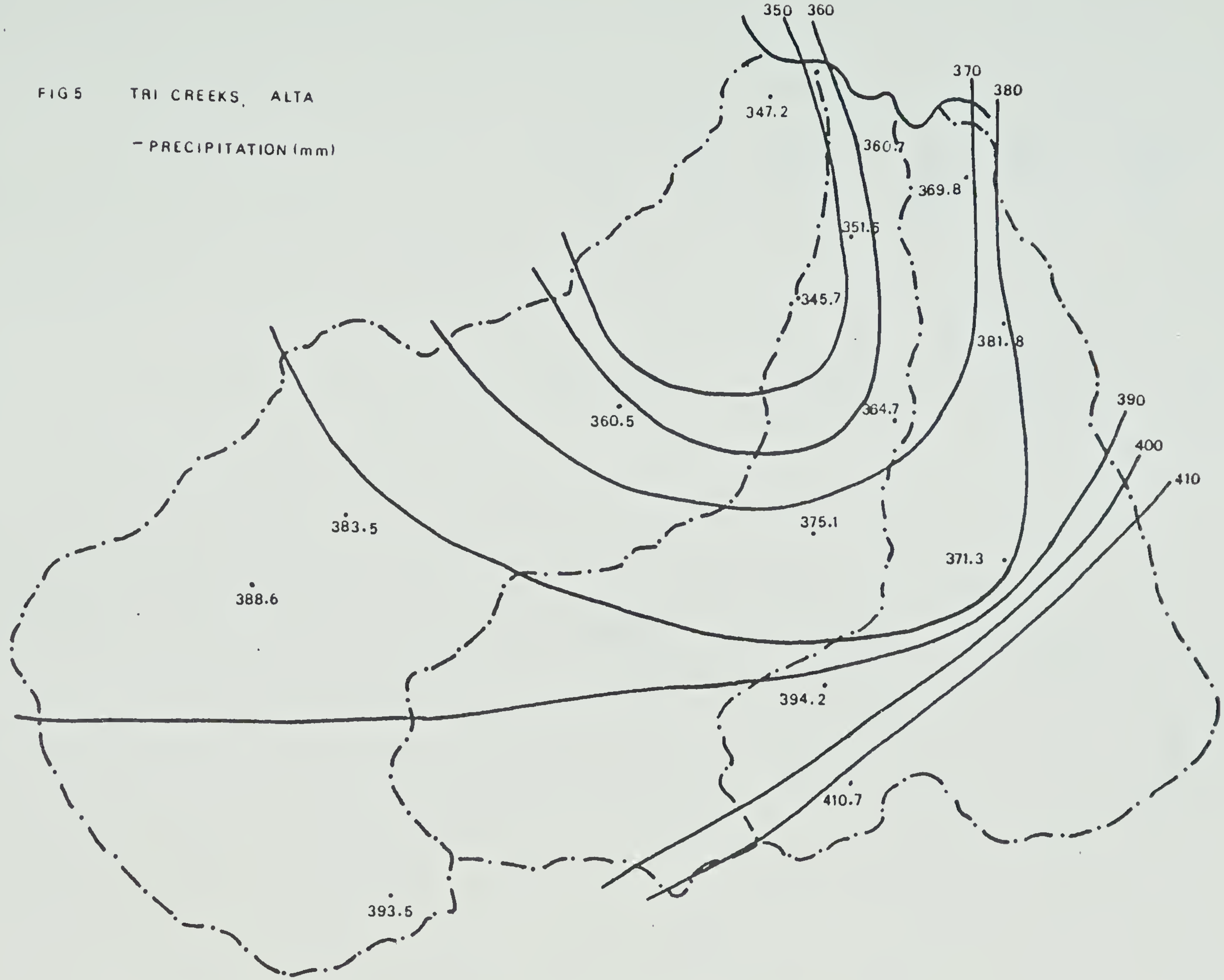


TABLE 14: Area Occupied by Hydrologic Units at Tri Creeks, Alta.

Unit	Area(km-sq)	% of Total Area
Wampus		
A	3.2	11.6
B	24.3	88.4
Total	27.5	
Deerlick		
A	1.4	10.2
B	12.3	89.8
Total	13.7	
Eunice		
A	1.8	11.3
B	14.1	88.7
Total	15.9	

shown in Table 15. Snowmelt contributions to runoff are listed in Table 16 and are plotted in Figure 6. No apparent trend was visible among sample sites, elevationally or areally, largely due to sample site distribution, therefore, an average value was taken as total input. Snowmelt contributions to each unit are shown in Table 17. In general, precipitation inputs, including snow, appear fairly uniform over the entire Tri Creeks area.

Similarly, interception varies little since it is estimated as a proportion (27 percent) of total precipitation.

Table 18 lists evapotranspiration losses for each unit based on the apportionment illustrated in Figure 7. Again, these values are generally uniform over the Tri Creeks area.

Contributions to the water balance through the depletion of stored soil moisture are indicated at all sample locations in Figure 8. Since no trends were discernible from the data collected over the basin, through statistical and visual examination, an average value was used for Unit B. No change in storage was assumed for Unit A, based on previous discussions (Table 19).

Potential runoff from each hydrologic unit was then calculated as shown in Table 17. For both Wampus and Deerlick, it can be seen that total contribution is largely a function of area (greater flows originating from larger areas). However, Eunice basin again shows irregularity . For the Eunice Creek watershed, Unit A appears to contribute the

TABLE 15: Seasonal Precipitation (mm) for Hydrologic Units at Tri Creeks, Alta.

Type	Ppt (mm)	Net Area Enclosed (km-sq)	Ppt Volumes	Avg. Unit Ppt	Avg. Basin Ppt
Wampus					
A	345	0.81	279.5		
	355	0.10	35.5		
	365	0.23	84.0		
	375	0.23	86.3		
	385	1.12	431.2		
	395	0.75	296.3	374	
B	345	3.54	1221.3		
	355	0.88	312.4		
	365	2.18	795.7		
	375	3.69	1383.7		
	385	8.14	3133.9		
	395	5.88	2322.6	377	377
Deerlick					
A	345	0.08	27.6		
	355	0.16	56.8		
	365	0.18	65.7		
	375	0.18	67.5		
	385	0.29	111.6		
	395	0.57	225.1	380	
B	345	0.65	224.2		
	355	1.01	358.5		
	365	1.46	532.9		
	375	3.04	1140.0		
	385	2.11	812.3		
	395	4.00	1580.0	379	379
Eunice					
A	365	0.08	29.2		
	375	0.47	176.2		
	385	0.34	130.9		
	395	0.39	154.0		
	405	0.16	64.8		
	415	0.36	149.4	391	
B	365	1.09	397.8		
	375	2.65	993.7		
	385	2.00	770.0		
	395	1.72	679.4		
	405	1.20	486.0		
	415	5.43	2253.4	396	396

TABLE 16: Mean April Snow-Water Equivalents for Tri Creeks, Alta. (1968-1978)

Station	Water Equivalents (mm)
Wampus	
C	98.6
E	94.5
F	88.6
G	67.3
Deerlick	
A	90.2
C	79.2
Eunice	
B	64.3
C	94.2
Mean	84.0

FIG 6 TRI CREEKS, ALTA

—SNOWMELT (mm)

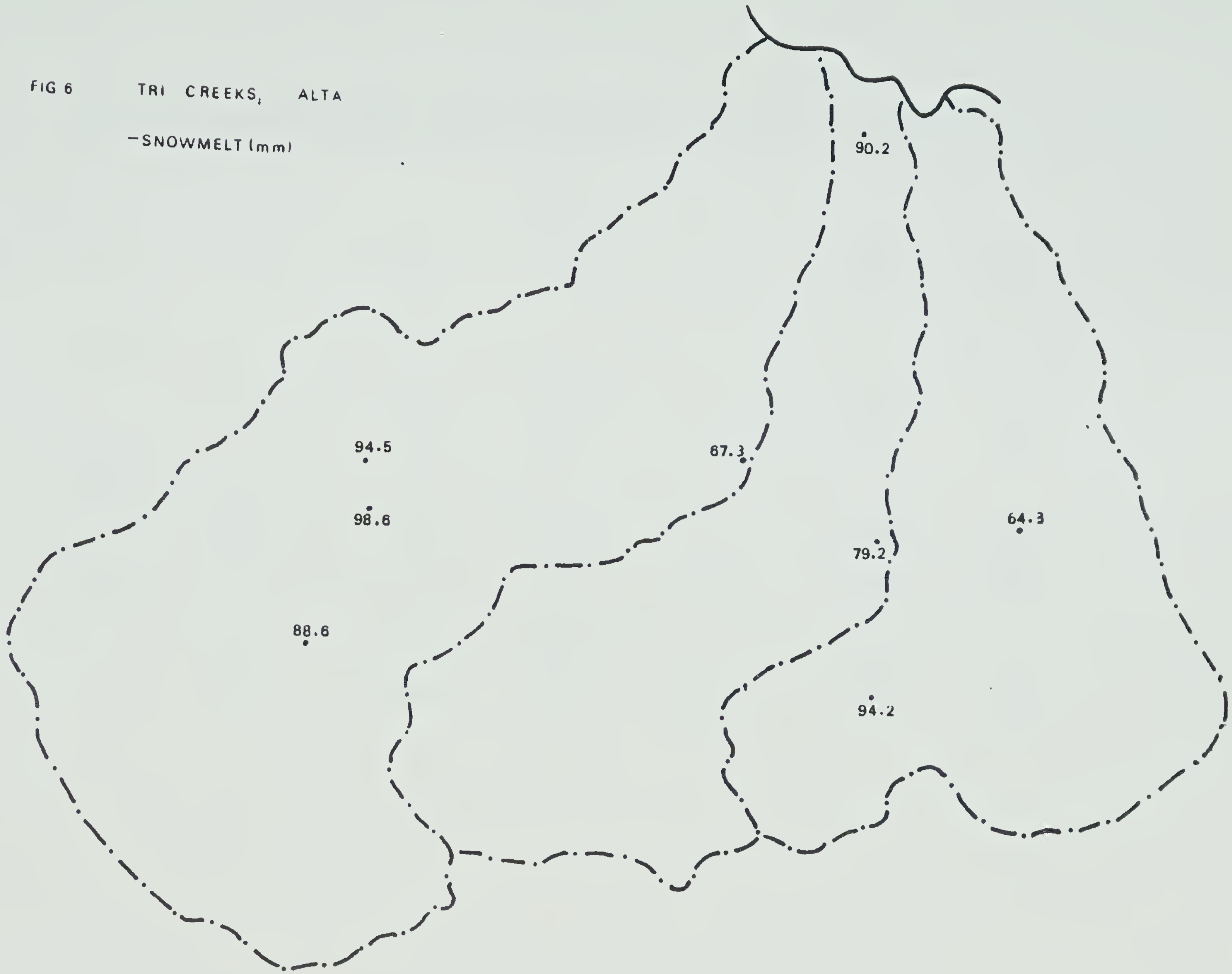


TABLE 17: Estimated Water Balances for Hydrologic Units at Tri Creeks, Alta.(area-mm)

Unit	Ppt	Et	I	S	SM	Qest.
Wampus						
A	377	174.4	101.8	0	84.6	185
B	378	171.1	102.1	30.3	84.6	220
Deerlick						
A	380	167.9	102.6	0	84.6	194
B	377	164.6	101.8	30.3	84.6	225
Eunice						
A	392	161.9	105.8	0	84.6	371
B	397	158.4	107.2	30.3	84.6	246

TABLE 18: Seasonal Evapotranspiration for Hydrologic Units at Tri Creeks, Alta.

Type	ET (mm)	Net Area (km-sq)	Area-mm	Unit Totals	Basin Total
Wampus					
A	157	0	0		
	167	2.34	390.8		
	194	0.88	170.7	174.4	
B	157	0.83	130.3		
	167	19.53	3261.5		
	194	3.98	772.1	171.1	171.5
Deerlick					
A	157	0.42	65.9		
	167	0.83	138.6		
	194	0.21	40.7	167.9	
B	157	6.37	1000.1		
	167	4.68	781.6		
	194	1.27	246.4	164.6	165.0
Eunice					
A	157	1.56	244.9		
	194	0.23	44.6	161.7	
B	157	13.55	2127.4		
	194	0.52	100.9	158.4	158.8

FIG 7 TRI CREEKS, ALTA.

— EVAPOTRANSPIRATION (mm)

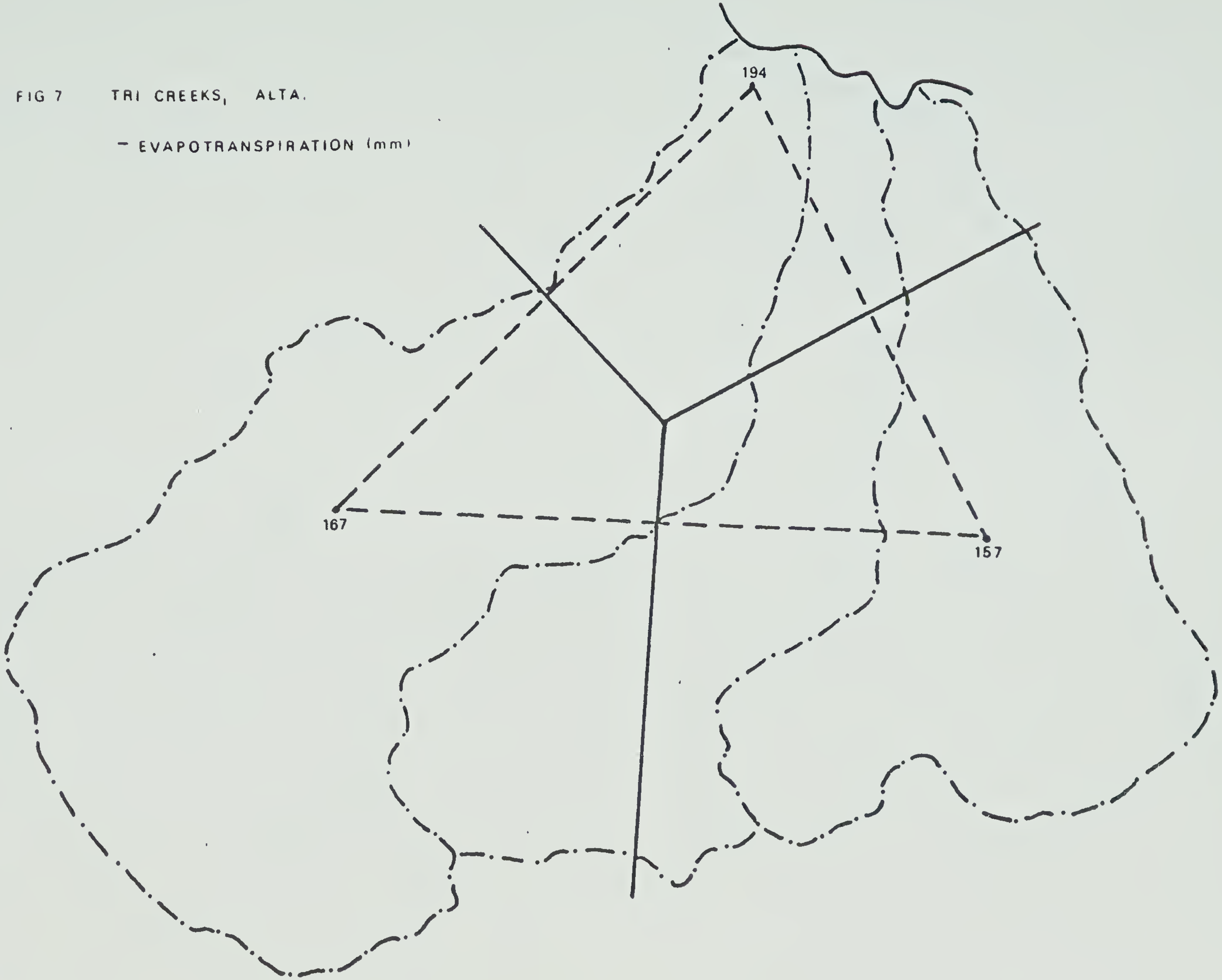


FIG 8 TRI CREEKS, ALTA

—STORAGE (mm)

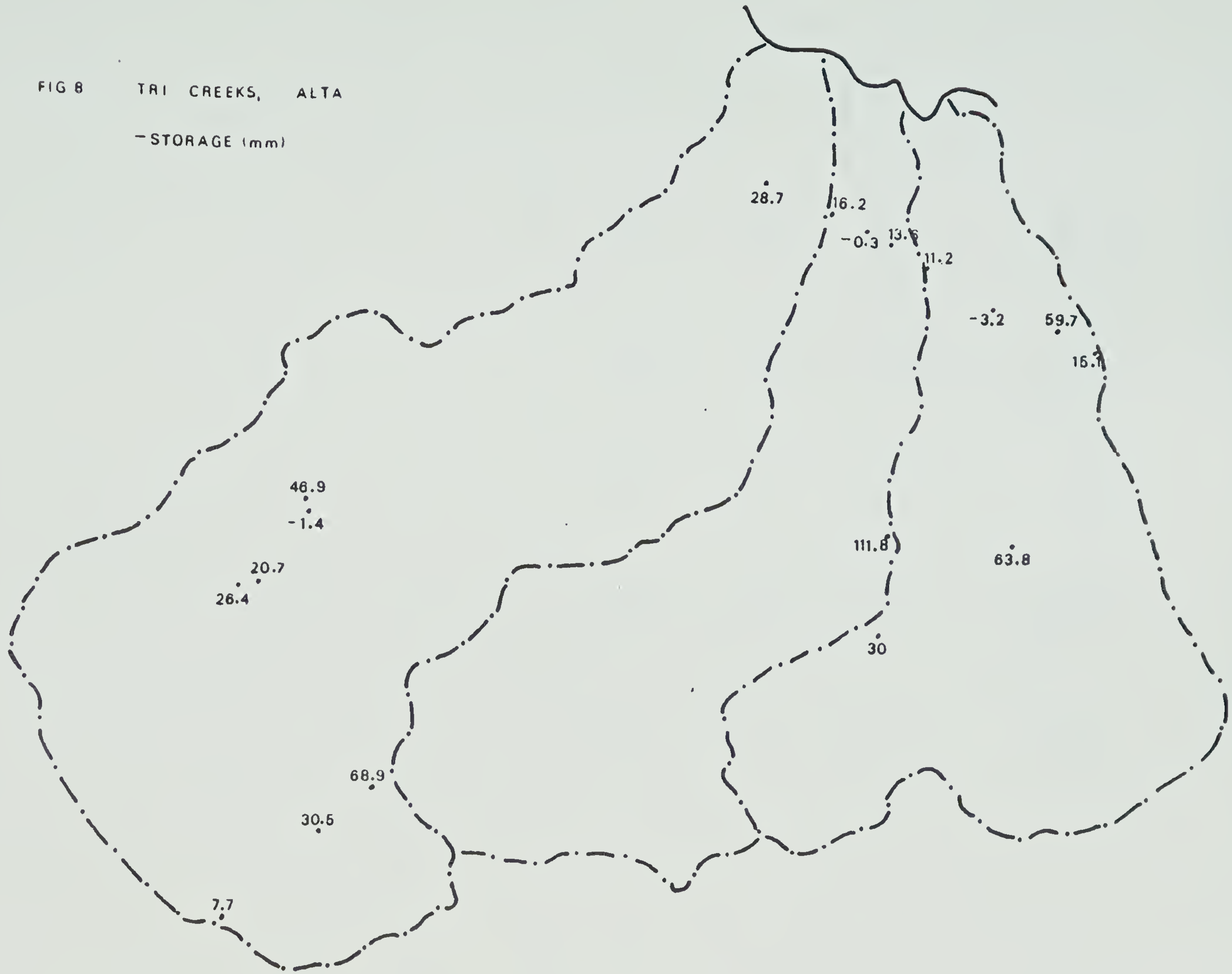


TABLE 19: Seasonal Storage Opportunity for Hydrologic Units at Tri Creeks, Alta.

Type	Storage (mm)	Net Area (km-sq)	Area-mm	Unit Totals	Basin Total
Wampus					
A	0	3.22	0	0	
B	30.3	24.34	737.5	30.0	26.8
Deerlick					
A	0	1.46	0	0	
B	30.0	12.32	373.3	30.3	27.1
Eunice					
A	0	1.79	0	0	
B	30.3	14.07	426.3	30.3	26.9

larger overall volume. This may in part be due to flow from the upslope region, to underestimation of losses, overestimation of precipitation and/or error in actual flow measurement.

It should be noted, at this time, that the techniques employed here do not allow the downslope routing of water movement. That is, one cannot determine the path taken by water from Unit B, what becomes of it once it has entered Unit A, or the proportion of flow from B which may be delayed in A. Nevertheless, general trends may still be observed.

E. Basin Water Balances

Table 20 provides a summary of estimated runoff, the deviation of estimated values from the actual and an index of hydrologic response for Unit A, B and each basin as a whole. Again the effect of area on total runoff volumes becomes apparent.

The total runoff volumes from each of the hydrologic units were area-weighted and summed to obtain a total for the basin in order to evaluate the results. It can be seen, that for both Wampus and Deerlick, the water balances used to represent each unit type lead to a good estimate of flow (ie. deviation from the actual is less than 5 percent). The overestimation problem discussed in the previous section again appears for Eunice.

Once area is held constant, it becomes quite evident

TABLE 20: Estimated Discharge and Response for Hydrologic Units (area-mm)

Unit	Qest.	% of Total	Qactual	Est. Dev.from Actual	Q mm per km-sq	Ppt	Hydr. Resp. (%)
Wampus							
A	185	10			57.8	377	49
B	220	90			9.1	378	58
Average	215		217	-1%		377.7	57
Deerlick							
A	194	9			138.6	380	51
B	225	91			18.3	377	60
Average	222		231	-4%		377.3	59
Eunice							
A	371	16			206.1	392	95
B	225	84			17.4	397	62
Average	260		197	32%		396.5	66

that runoff per unit-area of hydrologic Unit A, is substantially larger than that per unit of B. Runoff from a given area of Unit A is roughly 6, 8 and 12 times greater in Wampus, Deerlick and Eunice Creeks respectively, than from Unit B. This additional volume per unit area is probably a result of available storage being filled (any unit of input thus resulting in output) due to flow from upslope regions.

The tabulated hydrologic response values also show fairly consistent trends. Streamflow response to seasonal precipitation is similar over the three basins, ranging from 57 to 66 percent. Similarly, Unit B shows a response of 58 to 62 percent. Theoretically, that is what one might expect given the relative homogeneity of surficial materials over the Tri Creeks area. Under such circumstances water movement through these should be equal. Further, the proportion of incoming precipitation not available for runoff, as a consequence of vegetation in either of the two units, should be comparable in all three basins on a unit area basis. This also would result in similarity of response.

Response values calculated for Unit A appear consistent for Wampus and Deerlick basins (49 and 51 percent respectively). Note that the response value is calculated using estimated runoff for Unit A. The value obtained for Eunice is, however, substantially larger (95 percent) indicating that the proportion of rainfall becoming runoff is far greater than noted for all other cases. This could be due to overestimation of precipitation as suggested

previously, or a result of losses in Eunice to some other source than expressed in the water balance. This was discussed previously. The response values indicate that this additional loss appears to be occurring in the saturated zone. It is therefore, hypothesized that leakage, either as a result of geology or simply due to lack of channel control at the gauging site, is occurring towards the outlet of Eunice basin.

For both Wampus and Deerlick basins, hydrologic response values are 10 percent smaller for Unit A than B. This indicates that Unit A requires a greater proportion of incoming moisture (both from upslope and precipitation) to sustain flow (ie. soil moisture storage at a maximum). The position of this unit, ie. the valley bottom, and corresponding greater depth of material would result in such an increased moisture requirement.

F. General Comments

The stratification of the Tri Creeks area based on data collected during ecological classification provides an initial approach to understanding basin hydrology. As cited in the background section, basin morphology will, in some cases, provide an adequate picture of rates of water movement and approximate quantities of runoff from a watershed. However, through the superposition of vegetation the division of inputs into losses and storage, through the hydrologic cycle, can be made.

Vegetation can provide a simple indication of saturated zones within the Tri Creeks watershed. From the calculations presented in this thesis, it can be seen that runoff on a unit-area basis varies substantially between the saturated versus unsaturated zones. The saturated zone produced the greater volume of water per unit in the Tri Creeks area. Since area has such an overriding influence, this increased water potentially available for runoff in A seems to be obscured as a consequence of the large area occupied by B and resultant flow.

A distinct shortcoming of such a scheme is that it provides no indication of the manner or degree to which flow from Unit B affects that from A. Since Unit A is assumed saturated for most of the season, due to both incoming precipitation and unsaturated/saturated flow from Unit B, any additional rainfall would produce runoff. However, the magnitude of flow contributed by B which is necessary to maintain saturation cannot be determined at this point.

One may hypothesize that this is fairly substantial for the Tri Creeks area since the response index calculated for Unit A is smaller than that for Unit B in Wampus and Deerlick basins. In other words, the rate at which seasonal precipitation produces runoff in Unit A is reduced in comparison to B. This may be explained by reduced precipitation inputs over the season and a lag in the reduction of saturated flow rates. Consequently, the proportion of precipitation becoming runoff in Unit A would

decrease resulting in an average response values less than that shown for Unit B. In time, the decline in precipitation and the consequent diminishing inputs from upslope areas, would lead to a contraction in the extent of the saturated zone.

In relation to the necessity of a full scale ecological classification of watersheds, it would appear that if such data were available, interpretations regarding local hydrology could be readily made. However, in terms of water loss estimation, given the present rather crude state of the art, if such data were not available it is suggested that reconnaissance level information would also be suitable. The moderate slopes of watersheds such as Tri Creeks can result in rather simplistic stratification as illustrated in this thesis. No doubt, had elevational gradients been large, a greater and more pronounced diversity in vegetative associations would have existed.

Given the less diverse system, such as Tri Creeks, a fairly superficial identification of vegetation occurring in both the saturated and unsaturated zones would allow reasonably accurate mapping from areal photography under similar conditions as those noted in the study area. It appears from work done at Tri Creeks that for water balance approximation such mapping would be adequate. Soil samples could then be collected along several slope transects to identify vegetative community correspondance to physical soil properties. In order to make conclusive statements in

regards to relative water retention and loss within units delineated, the sample size assigned to each unit should be large enough to allow meaningful statistical analyses. The number and location of samples should, therefore, be determined after unit delineation.

It is further suggested that some estimate of actual water status, depletion and movement rates be made in order to provide an understanding of actual water movement within and among units over the season. Similarly, the actual area of the saturated zone may expand and contract depending on storm intensity and duration, as well as antecedent conditions. Determination of the extent of the saturated zone under varied conditions would lead to a greater understanding of actual response within each hydrologic unit.

G. Results Based on the Rational Formula

Though variability in the actual extent of the saturated zone over the season is left for subsequent measurement and study, the hypothesis that this zone "expands and contracts" appears to be supported by several calculations using the rational formula. Stormflow values calculated using the rational formula are given in Table 21 (original data in Appendix 5) for spring and summer seasons. From this table it is noted that during the spring season the rational method overestimated actual stormflow 60 percent of the time, on the average by 0.52 cms (19 cfs). In

TABLE 2i: Estimated vs. Actual Stormflow Derived from the Rational Formula for Tri Creeks, Alta.

Spring				Summer			
Qact	Qest(A)	Residual	Ratio (Est/Act)	Qact	Qest(A)	Residual	Ratio (Est/Act)
10.7	41.0	+30.3	3.8	8.8	24.6	+15.8	2.8
9.6	24.6	+15.0	2.6	22.6	41.0	+18.4	1.8
42.6	32.8	- 9.8	0.8	34.5	49.2	+14.7	1.4
11.6	49.2	+37.6	4.2	2.8	24.6	+21.8	8.8
49.9	57.3	+ 7.4	1.1	28.2	41.0	+12.8	1.5
62.9	24.6	-38.3	0.4	10.1	90.1	+80.0	8.9
9.9	32.8	+22.9	3.3	13.6	32.8	+19.2	2.4
12.5	24.6	+12.1	2.0	10.8	65.5	+54.7	6.1
42.2	32.8	- 9.4	0.8	19.4	32.8	+13.4	1.7
67.4	41.0	-26.4	0.6	11.9	41.0	+29.1	3.4
7.9	7.2	- 0.7	0.9	4.5	7.2	+ 2.7	1.6
7.1	10.8	+ 3.7	1.5	13.2	14.3	+ 1.1	1.1
12.8	14.3	+ 1.5	1.1	27.0	21.5	- 5.5	0.8
30.1	14.3	-15.8	0.5	1.0	7.2	+ 6.2	7.2
10.0	39.4	+29.4	3.9	22.2	21.5	- 0.7	1.0
11.1	10.8	- 0.3	1.0	11.5	21.5	+10.0	1.9
7.6	14.3	+ 6.7	1.9	10.0	10.8	+ 0.8	1.1
25.1	14.3	-10.8	0.6	2.6	7.2	+ 4.6	2.8
62.9	21.5	-41.4	0.3	11.6	14.3	+ 2.7	1.2
38.1	10.6	-27.5	0.3	29.4	35.8	+ 6.4	1.2
9.7	18.4	+ 8.7	1.9	21.0	27.6	+ 6.6	1.3
16.2	23.0	+ 6.8	1.4	12.3	13.8	+ 1.5	1.1
5.8	46.1	+40.3	7.9	2.6	9.2	+ 6.6	3.5
9.4	23.0	+13.6	2.4	7.1	27.6	+20.5	3.9
10.8	27.6	+16.8	2.6	9.4	9.2	- 0.2	1.0
71.8	27.6	-44.2	0.4	13.4	27.6	+14.2	2.1
3.7	64.5	+60.8	17.4	4.0	13.8	+ 9.8	3.5
6.9	13.8	+ 6.9	2.0	8.8	9.2	+ 0.4	1.0
5.5	18.4	+12.9	3.3	29.7	32.2	+ 2.5	1.1
28.4	13.8	-14.6	0.5	2.7	9.2	+ 6.5	3.4

summer, overestimation occurred for 90 percent of the storms evaluated, by roughly 0.40 cms (14 cfs) on the average. This indicates that, based on the contributing area mapped, additional losses must be occurring which are not accounted for by the given equation, such as storage. Since this loss appears to be increasing over the season it may be hypothesized that additional moisture is required as the season progresses to maintain the saturated extent of the contributing area due to increased rates of drawdown between storms. This relative increase in the depletion of water may be due to greater evaporative losses and reduced storm frequency. Alternately (or in combination with), the actual extent of the contributing area may be decreasing over the season.

Since, with the information available, the hypothesized losses could not be investigated, the difference in mapped versus calculated contributing areas were considered. These values are tabulated in Table 22. In spring, the contributing area necessary to produce the measured peak flow is generally less than that mapped. According to the rational formula the area mapped was greater than the 'actual' contributing area 60 percent of the time. A similar situation occurred for summer storms. For 90 percent of the storms, the area mapped was larger than that suggested by the rational formula. On the average, the mapped area was 120 ha (300 acres) larger that that indicated by the formula. This consitutes an area 37, 86 and 67 percent

TABLE 22: Estimated vs. Actual Contributing Area Derived from the Rational Formula for Tri Creeks, Alta.

Spring				Summer			
Aact	Aest	Residual	Ratio (Est/Act)	Aact	Aest	Residual	Ratio (Est/Act)
800	214	-586	0.3	800	293	-507	0.4
800	320	-480	0.4	800	452	-348	0.6
800	1065	+265	1.3	800	575	-225	0.7
800	193	-607	0.2	800	93	-707	0.1
800	713	- 87	0.9	800	564	-236	0.7
800	2097	+1297	2.6	800	92	-708	0.1
800	248	-552	0.3	800	340	-460	0.4
800	417	-383	0.5	800	135	-665	0.2
800	1055	+255	1.3	800	485	-315	0.6
800	1348	+548	1.7	800	238	-562	0.3
350	395	+ 45	1.1	350	225	-125	0.6
350	237	-113	0.7	350	330	- 20	0.9
350	320	- 30	0.9	350	450	+100	1.3
350	753	+403	2.2	350	50	-300	0.1
350	91	-259	0.3	350	370	+ 20	1.1
350	370	+ 20	1.1	350	192	-158	0.5
350	190	-160	0.5	350	333	- 17	1.0
350	628	+278	1.8	350	130	-220	0.4
350	1048	+698	3.0	350	290	- 60	0.8
350	1270	+920	3.6	350	294	- 56	0.8
450	243	-207	0.5	450	350	-100	0.8
450	324	-126	0.7	450	410	- 40	0.9
450	58	-392	0.1	450	130	-320	0.3
450	188	-262	0.4	450	118	-332	0.3
450	180	-270	0.4	450	470	+ 20	1.0
450	1197	+747	2.7	450	223	-227	0.5
450	26	-424	0.1	450	133	-317	0.3
450	230	-220	0.5	450	440	- 10	1.0
450	138	-312	0.3	450	424	- 26	0.9
450	947	+497	2.1	450	135	-315	0.3

larger than that mapped or, 4, 8 and 8 percent of the total basin area of Wampus, Deerlick and Eunice Creeks respectively.

If the mapped were larger that the actual contributing area, this would explain at least in part, the overestimation of flow by this method (shown in Table 21). In turn, this would suggest that the vegetative associations used in characterizing the contributing area may also be indicative of a fringe area or intermediate zone. Here, saturated conditions would occur over a sufficient period to result in wet-site plant communities but would presumably exhibit unsaturated conditions between storms or over some portion of the season. The frequency of saturation of this intermediate zone would decrease over the spring to summer seasons. Further, the fringe area would expand in direct relation to the contraction of the saturated zone as the season progresses. This would explain, to some extent, the increased frequency of flow overestimation during the summer.

Use of the contributing area as a tool for describing variability in peak flow was examined more quantitatively using stepwise regression analyses. Again, 30 storms in both the spring and summer season were examined. The initial analyses included all independent variables; measures of precipitation, contributing area and antecendent conditions. This was done as a means of sorting out those variables accounting for the greatest proportion of variability in

stormflow. Several variables used were highly intercorrelated (Appendix 6) thus the assumptions basic to this form of analysis were not met. These variables were eliminated for the second run.

From the analyses presented in Tables 23 and 24 it can be seen that precipitation, antecedent precipitation conditions and the mapped contributing area account for the greatest variability in spring stormflow. For spring stormflow, antecedent conditions appear to be highly significant at a probability of 0.05 (Table 23). At a probability of 0.01, the actual extent of the contributing area also becomes significant. The actual magnitude of precipitation does not appear to be a controlling factor in this case. This may be a function of the selected storms or the already saturated conditions. Under such conditions it might be hypothesized that any additional precipitation received above a certain level would result in expansion of the saturated zone rather than becoming runoff. As shown in Table 23, the antecedent conditions, average contributing area, and total incoming precipitation only accounted for 56 percent of the variability in stormflow. This may have been improved had actual variation in contributing area extent been known. In itself, the average size of the contributing area did not substantially enhance the prediction of flow based on the selected parameters, ie. it explained an additional 9 percent of the variability. It would appear that hillslope processes may be more dynamic factors than

TABLE 24: Summer Stormflow Regression Analyses for Tri Creeks, Alta.

Variables			Statistics					
X3	X2	X1	Mult-R	R-Sq.	R-Sq.Change	Simple R		F
x	x	x	0.8966	0.8040	0.0438	0.1830	X1	76.824 ss
	x	x	0.8719	0.7601	0.0676	0.4459	X2	8.036 ss
		x	0.8322	0.6925	0.6925	0.8322	X3	5.812 ss

where:

X1 = Precipitation

X2 = Antecendent Precipitation/Day

X3 = Mapped Contributing Area

ss = significant at p=0.05

TABLE 23: Spring Stormflow Regression Analyses for Tri Creeks, Alta.

Variables			Statistics					
X3	X2	X1	Mult-R	R-Sq.	R-Sq.Change	Simple R	F	
x	x	x	0.5627	0.3167	0.0136	-0.0716	X1	9.323 ss
	x	x	0.5505	0.3031	0.0928	0.2667	X2	2.978 s
		x	0.4586	0.2103	0.2103	0.4586	X3	0.517

where:

X1 = Antecedent Precipitation/Day

X2 = Mapped Contributing Area

X3 = Precipitation

ss = significant at p=0.05

s = significant at p=0.10

actual contributing area early in the season. With the data available, however, one cannot suggest the magnitude or form of contribution resulting from the unsaturated zone (Unit B).

During the summer season, the complications exhibited in the spring analysis become minor. Table 24 indicates good correlation between average antecendent precipitation, contributing area, total precipitation and stormflow. All independent variables are also highly significant in their contribution to the predictability of flow (see F-statistics). Together they account for approximately 90 percent of variability in summer stormflow. It may, therefore, be suggested that late in the season the average area given as contributing to flow fluctuates little and that this zone plays the key role in stormflow generation while upslope effects diminish over the season.

VII. SUMMARY OF STUDY RESULTS

The following is a brief summary of findings resulting from this study:

1. Data obtained through ecological classification appear to provide a basis for the designation of distinct hydrologic response zones within the Tri Creeks watershed.
2. Small, moderately sloping basins, such as those at Tri Creeks, may be stratified into two basic hydrologic units, ie. a saturated and unsaturated zone, each of which contain characteristic vegetative associations.
3. The saturated zone covers valley bottom areas and borders ephemeral channels, seeps and springs. The remaining watershed slopes may be designated as unsaturated.
4. On a unit-area basis, water potentially available for flow is larger in the saturated zone than that from hillslope areas.
5. The saturated zone, through its slightly lower response index appears to require increased proportions of incoming precipitation, as well as, flow from upslope areas in order to maintain its areal extent. As these inputs decline over the summer season, it was hypothesized that the extent of the saturated zone would also decrease.
6. The water balance approach appears to provide a reasonable tool for estimation of runoff from selected

portions of a watershed. This technique, based on actual processes, allows for a greater understanding of within unit inputs and losses.

7. Use of the rational formula for peak flow estimation appears to overestimate peak volumes, for the majority of storms, throughout the season based on the area of the saturated zone as mapped.
8. Vegetation can be used to delineate the maximum extent of the contributing area. Therefore, since this zone appears to contract over the season it is hypothesized that a fringe or intermediate zone of periodic saturation exists.
9. Spring stormflow appears to be influenced by hillslope processes to a large extent. This seems to be substantiated by the regression analyses of contributing area, antecedent conditions and precipitation as predictors of flow and the resultant low correlation coefficients (ie. 0.56).
10. The regression analyses further indicate that variability in summer stormflow is for the most part (90 percent) explained by antecendent conditions and total precipitation over the saturated zone in the Tri Creeks area. This zone may thus be assumed to dominate in stormflow generation late in the season.
11. It is recommended that studies involving the measurement of actual, in-field, moisture would lead to an understanding of interactions between flow from

unsaturated zones into and through saturated areas.

12. On a seasonal basis, the designation of such zones as suggested here, would be of value in terms of streamflow maintenance and the planning of management activities.

CONCLUSIONS

In the past, streamflow estimates for ungauged areas have been made using morphologic, watershed parameters and regression coefficients, obtained through similar analyses of neighboring monitored streams, as predictors. This technique is rather artificial in nature and does not explain the actual inputs and losses, through the hydrologic cycle, to a watershed. Thus, the regressions developed provided no indication of the origins of the flow values predicted. Even though the technique was perhaps adequate for the prediction of total runoff from a basin, for site specific management it does not allow the interpretation of runoff on a localized scale.

Use of a water balance approach leads to the estimation of all major inputs to and losses from the watershed system. In turn these are influenced by local soils and vegetation as well as overall morphology. Soil moisture conditions are further expressed by vegetative associations.

Data collected during such classification projects as the biogeoclimatic appear to provide information useable in the correlation of vegetative associations with variability in water balance components. This allows the stratification of a watershed into zones of supposed hydrologic homogeneity. For the Tri Creeks area, two distinct zones exist; a saturated valley bottom zone containing a substantially greater volume of water potentially available for runoff per unit-area than the second zone, which is an

area of unsaturated conditions covering the remaining watershed slopes.

Runoff can then be estimated for each delineated zone. This would lead to an appreciation of moisture regimes over a basin rather than simply at the outlet. Such an understanding may be valuable in the application of land management schemes.

Use of the rational formula provided additional insight into the area covered by the saturated zone, for both spring and summer storms. The use of vegetation for contributing area delineation may also include an intermediate zone of periodic saturation. This zone would expand in relation to reduction in actual contributing area over the season.

Spring stormflow seems to be influenced by hillslope contributions and/or changes in storage not accounted for by the rational formula. Stratification based on biogeoclimatic data, where available, appears to provide a good estimation of the primary contributing area for summer storms.

Further study in a greater number of watersheds, the collection of moisture data throughout the season (in both the saturated and unsaturated zones) and the quantification of saturated zone expansion and contraction would allow increased accuracy in response estimation and understanding of local hydrology.

Literature Cited

Anderson,H.W., M.D.Hoover and K.G.Reinhart. 1976. Forests and Water: effects of forest management on floods, sedimentation and water supply. U.S.D.A.-Forest Service General Technical Report PSW-18.

Armson,K.A. 1977. Forest Soils: Properties and Processes. Univ. of Toronto Press. Toronto.

Berglund,E.R. and A.C.Mace. 1976. Diurnal Albedo of Black Spruce and Sphagnum-Sedge Bogs. J. of Frst. Res. Vol.6 No.3, Sept.1976.

Black,C.A.ed. 1965.Methods of Soil Analysis. Am. Soc. of Agronomy, Madison, Wisc.

Briere,D. 1979. The Stratification of Forested Landscapes for Intensive Management: Development and Application. PhD. Thesis, Fac. of Forestry, Univ. of B.C., Vancouver.

Bruce,J. and R.Clark. 1966. Introduction to Hydrometeorology. Pergamon Press. Oxford.

Buffo,J., L.J.Fritschen and J.L.Murphy. 1972. Direct Solar Radiation on Various Slopes from 0 to 60 Degrees North Latitude. U.S.D.A.-Forest Service Res. Paper PNW-142. Portland, Oregon.

Canadian Soil Survey Committee on Soil Classification. 1978. Can. Dept. Agric. Publ. 1646. Supply and Services Canada, Ottawa, Ont.

Chang,J.H. 1968. Climate and Agriculture: an ecological survey. Aldine, Chicago.

Chow,V.T. 1964. Handbook of Applied Hydrology. McGraw Hill

Book Co., New York.

Currie,D.V. 1969. Hydrogeology of Tri Creek Basin, Alta. M.Sc. Thesis, Dept. of Geology, Univ. of Alta., Edmonton.

Dunne,T. and R.D.Black. 1970. Partial Area Contributions to Storm Runoff in a Small New England Watershed. Water Resources Research, Vol.6 No.5, Oct.1970.

Dunne,T. and L.B.Leopold. 1978. Water in Environmental Planning. W.H.Freeman and Co., San Francisco.

Dumanski,J., T.M.Macyk, C.F.Veauvy and J.D.Lindsay. 1972. Soil Survey and Land Evaluation of Hinton-Edson Area, Alta. Report No.31, Alta. Soil Survey. Dept. of Extension, Univ. of Alta., Edmonton.

Gay, L.W. 1972. Energy Flux Studies in a Coniferous Forest Ecosystem. In: Research on Coniferous Forest Ecosystems, Proceedings of a Symposium , Ed: Franklin,J.F., L.J.Dempster and R.H.Waring. PNW Forest and Range Exp. Sta., Portland, Oregon.

Golding,D.L. and C.R.Stanton. 1972. Water Storage in the Forest Floor of Subalpine Forests of Alta. Can.J.For.Res.2:1-6.

Gray,D.M. 1973. Handbook on the Principles of Hydrology. NRC. Reprinted by Water Information Centre Inc., New York.

Green,B. 1978. Personnal communication. B.C.F.S.-Research Div. Kamploops, B.C.

Gregory,A.N. and D.E.Walling. 1973. Drainage Basin Form and

Process: a geomorphological appraoch. Edward Arnold (Publ.) Ltd., London.

Hack,J.T. and J.C.Goodlett. 1960. Geomorphology and Forest Ecology of a Mountain Region in the Central Appalachians. Geol. Survey Prof. Paper. U.S. Govt. Printing Office, Wash.

Helvey,J.D., J.D.Hewlett and J.E.Douglass. 1972. Predicting Soil Moisture in the Southern Appalachians. Proc. Soil Sci. Am. 36.

Hewlett,J.D. and W.L.Nutter. 1969. An Outline of Forest Hydrology. Univ. of Georgia Press. Athens, Georgia.

Jablonski,P.D. 1978. The Tri Creeks Watershed: A Study into the Effects of Logging on the Physical, Chemical and Biotic Conditions of Three Alberta Eastslopes Streams. Rep.No.1. Alta. Energy and Natural Resources. Frst. Land Use Branch.

Jarvis,P.G., G.B.James and J.J.Landsberg. 1976. Coniferous Forest. In: Monteith,J.L.(Ed.) 1976. Vegetation and the Atmosphere. Vol.2 - Case Studies. Academic Press, London.

Kirkby,M.J.(Ed.) 1978. Hillslope Hydrology. John Wiley and Sons Ltd. G.B.

Kojima,S. and V.J.Krajina. 1975. Vegetation and Environment in Strathcona Park. Syesis, Vol.8(Suppl.1).

Krajina,V.J. 1970. Ecology of Western North America. Dept. of Botany, Univ. of B.C., Vancouver.

Krumlik,G.J., J.D.Johnson and L.D.Lemmen. 1979.

Biogeoclimatic Ecosystem Classification of Alberta - Progress Report for 1978/79 Fiscal Year. C.F.S.-Environment Canada at NFRC, Edmonton, Alta.

Langbein,W.D. 1947. Topographic Characteristics of Drainage Basins. Water Supply Paper 968-C. U.S. Dept. of Interior, Wash.

Linsley,R.K., M.A.Kohler and J.L.H.Paulhus. 1975. Hydrology for Engineers. 2nd.Ed. McGraw Hill Book Co., New York.

Lull,H.W. and W.E.Sopper. 1967. Prediction of Average Anuual and Seasonal Streamflow of Physiographic Units in the Northeast. In: Sopper,W.E. and H.W. Lull(Eds.). Forest Hydrology. Pergamon Press, Oxford. Book Co., New York.

McBoyle,G.(Ed.) 1973. Climate in Review. Houghton Mifflin Co. Boston.

McCormack,R.J. 1965. The Canada Land Inventory, objectives and organization. Report No.1. Dept. of Regional Economic Expansion.

Morisawa,M. 1968. Streams - their dynamics and morphology. McGraw Hill Book Co., New York.

Nie,N.H. 1975. SPSS: Statistical Package for the Social Sciences. McGraw Hill Book Co., New York.

Rothacher,J. 1963. Net Precipitation Under a Douglas-fir Forest. For.Sci.9.

Satterlund,D.R. 1967. Forest Types and Potential Runoff. In: Sopper, W.E. and H.W.Lull(Eds.). Forest Hydrology. Pergamon Press, Oxford.

Slaymaker,O. and L.M.Lavkulich. 1978. A Review of Land Use -

Water Quality Interrelationships and a Proposed Method for their Study. Westwater Res. Centre Tech. Rep. No.13. Vancouver, B.C.

Sopper,W.E. 1971. Watershed Management. National Tech. Info. Serv. Report NWC71-008. Springfield, Va.

Strahler,A.N. 1964. Quantitative Geomorphology of Drainage Basins and Channel Networks. In: Chow,V.T. Handbook of Applied Hydrology. McGraw Hill Book Co., New York.

Swift,L.W. 1960. The Effects of Mountain Topography Upon Solar Energy Theoretically Available for Evapotranspiration. M.Sc. Thesis, N.C. State College, Raleigh, N.C. Original not seen. From: Douglass,J.E. 1967. Effects of Species and Arrangement of Forests on Evapotranspiration. In: Sopper,W.E. and H.W.Lull(Eds.). Forest Hydrology. Pergamon Press, Oxford.

Viessman,W., J.W.Knapp, G.L.Lewis and T.E.Harbaugh. 1977. Introduction to Hydrology. 2nd Ed. Harper and Row Publ., New York.

Wishart,D. 1978. Clustan: User Manual. 3rd Ed. Inter-Univ./Res. Councils Series, Report No.47. Program Library Unit, Edinburgh Univ., Scot.

Zinke,P.J. 1960. The Soil-Vegetation Survey as a Means of Classifying Land for Multiple-Use Forestry. In: Proc. 5th World Forestry Congress,

Appendix 1 - Sample Plot Sheet

STAND DESCRIPTION

Plot No.:

Date: ______ Recorded by: ______ Size: ______ m^2

Location: ______

Township: ______ Nearest town: ______ km

Latitude: ______ Longitude: ______ Forest cover map: ______

Nearest climatic stn.: ______ Direction: ______ Distance: ______ km

Macroclimate (est.): ______ Air photo No.: ______

Biogeoclimatic zone: ______ / subzone ______ / ______

Biogeocoenosis (provisional): ______

GENERAL PHYSIOGRAPHY: Elevation: ______ m, Aspect: ______, Slope: ______ °

Relief shape: ______ Landform: ______

Topographic position: ______

VEGETATION: Physiognomy:

Vegetation stratification

Strata		height range	coverage	total coverage	Canopy closure
A: Tree	A[1]	(- m)	______ %	A: ______ %	______ %
	A[2]	(5m - m)	______ %		
B: Shrub	B[1]	(2m - 5m)	______ %	B: ______ %	
	B[2]	(less than 2m)	______ %		
C: Herb	C	(herbaceous)	______ %	C: ______ %	
D: Moss	Db	(mosses)	______ %	D: ______ %	
	D[1]	(lichens)	______ %		

E: Epiphytes: abundant ______ moderate ______ scarce ______

Ground cover other than vegetation

Humus ______ %, mineral soil ______ %, decayed wood ______ %, water ______ %

Stones & rocks ______ %, others ( ) ______ %

Snow ______, water: running ______, stagnant ______, seeping ______

Frozen ground: ______ depth to ______ cm.

Regeneration: strong ______, moderate ______, weak ______, none ______

Species: ______

Successional stage: early ______, intermediate ______, advanced ______, mature ______

STAND DESCRIPTION

Plot No.:

Date: Recorded by:

General description of stand

VEGETATION ANALYSIS

Plot No.:

Date: ____________________ Recorded by: ____________________

er	Species	Coverage %	D-K cl.	Vgr	Fl	Fr	Remarks

SOIL DESCRIPTION

Plot No.:

Date: ______________________ Recorded by: ______________________

Biogeocoenosis (provisional): ______________________

Soil classification: ______________________

Parent material (mode of origin): ______________________

Geological characteristics: ______________________

Drainage: ______________ Hygrotype: ______________ Trophotope: ______________

Impermeable layer: ______________ depth to: __________cm. Erosion: ______________

Ground water depth: __________cm, water sample No.: __________ Depth to lime ______________cm

Humus: type ______________ thickness (cm): L ________ F ________ H ________ .

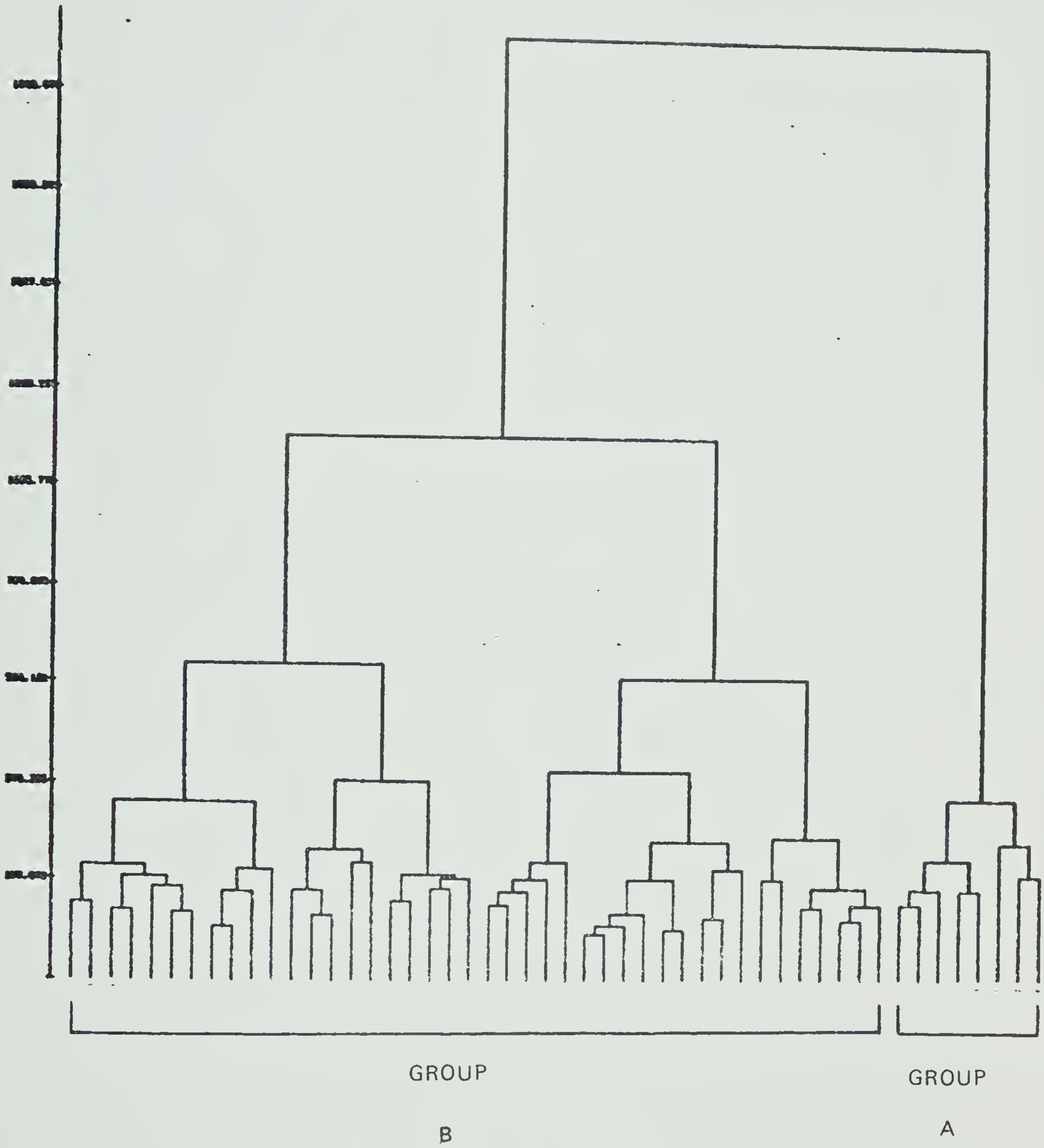
SOIL DESCRIPTIONS

Plot No.:

Date: ____________________ Recorded by: ____________________

	1	2	3	4	5	6
Horizon						
Sample No.						
Depth						
Thickness						
Boundary						
Color						
Mottles						
Structure						
Texture						
Stoniness						
Root distr.						
pH						
Effervescens						

Appendix 2 - Vegetation Clusters


GROUP
B
GROUP
A

Appendix 3 - Phytosociologic Table

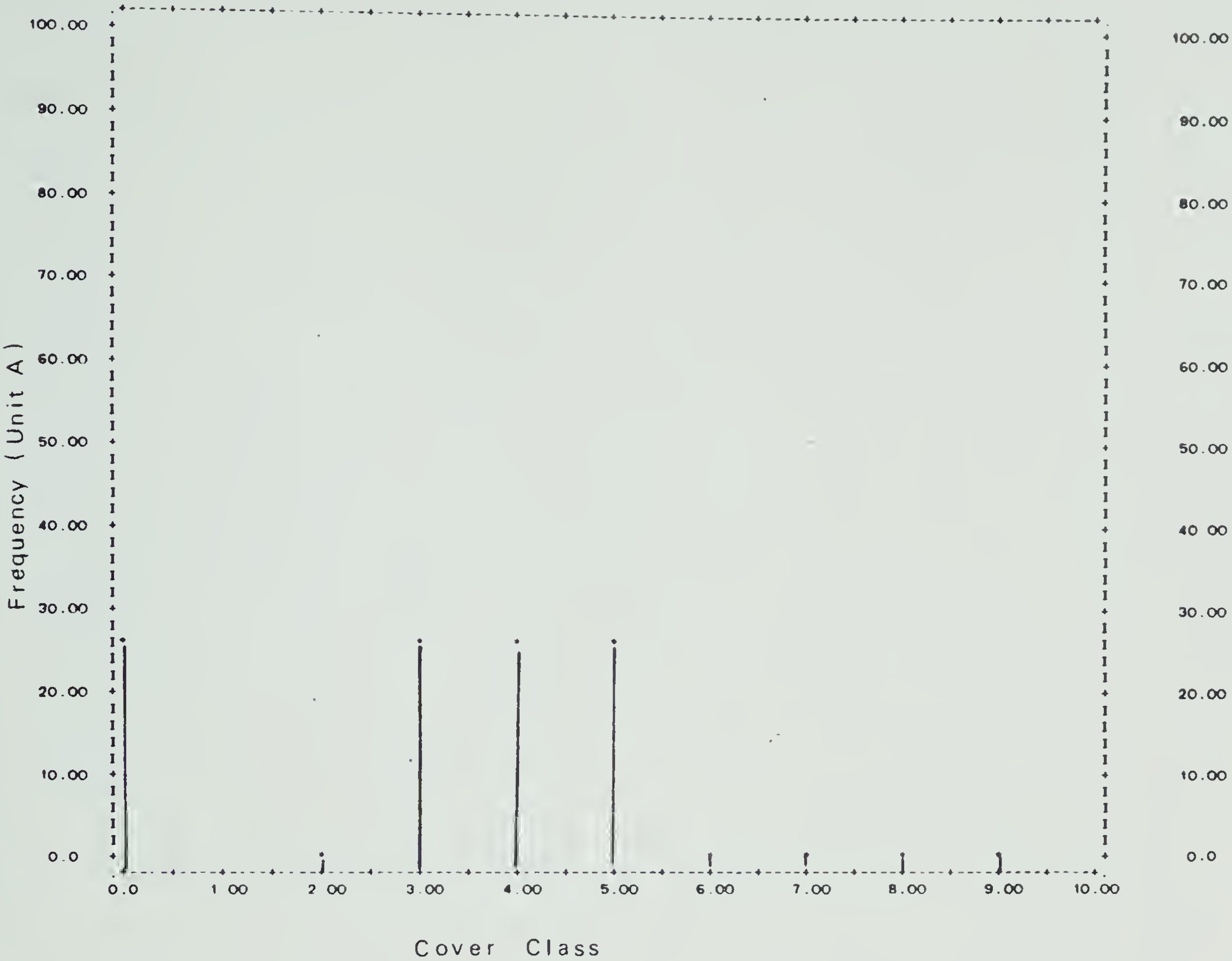
	GROUP A								GROUP B								GROUP B																																	
	9	34	35	37	38	40	42	49	1	2	3	4	5	6	7	8	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	36	39	41	43	44	45	46	47	48	50
Carex sps.	10				2			10																																										
Erigaron sps.					1			5																																										
Geum triflorum		5																																																
Oxytropus sps.			1		1	2		1																																										
Senecio triangularis								5																																										
Thalictrum sps.	5	5																																																
Abies lasiocarpa									2		10	16	26			2			+	+			2				2	5	6	16	2	+	1		6	5	2	1	+	+	+					4	3	2	2	
Actea rubra															1																																			
Alnus crispa											5			+		1			2	2	30	5						5	2	10	20	20	5	40		15	1	2		2	2	+	+			+	1			
Amelanchier alnifolia															2																											7			+					
Antennaria neglecta																																		+																
Antennaria parvifolia																																			1															
Aquilegia formosa																																		1	3															
Arnica latifolia																																												+						
Auralia nudicaulis															2																																			
Campanula sps.																																			5			1				1							1	
Eriophorium angustifolium																								2																		1								
Juniperus communis									5																													1				10		2						
Listera cordata									+			1				1							+					1	1		5	+	2			2			2	2	.2			1					1	
Lycopodium sps.									10			5	6			2							1		5		5	2		2	2	6	6			2		2	6								2			
Maianthemum canadense										2					5																							+			.2	5								
Menziessia faruginea									+		+	15				+											5				2	3	1	+					1	2										
Moneses uniflora																										2			+																					
Pedicularis parviflora													2										1		5																									
Pedicularis sagittatus																																											2							
Phyllodoce glanduliflora																							+																											
Picea glauca																	+				+	+																				+		4					+	
Picea glauca x engelmannii																									+	2	3		2	5																5	1			+
Pinus contorta									1	+						1	+		+		+				+	+					1		2	5	+			1	+	+	+	+	2	1						+
Pyrola asarifolia															2		1		25	15	5	3	+					2	1	2			2	1			2					1				2	2		2	2
Pyrola secunda											5	5			2					1			2			1		2	1	2	1		2			2	1	1			3					5	5	2	2	2
Pyrola virens									1		2							+		1						1		1	1				1																	
Rhododendron albiflorum																					2																													
Rubus chamaemorus																																																		+
Rubus strugosis																							5																											
Sambucus sps.																			+												+						1									+				
Sorbus scopulina																+																		2													2			1
Spirea lucida														5	5																1	2																		
Vaccinium membranaceum									2		5	20	5			5					10										10	10	16	10		10	1			5	16					5	2	5		2
Vaccinium myrtilloides										10													2		2																									

	GROUP A								GROUP B							
	9	34	35	37	38	40	42	49	1	2	3	4	5	6	7	8
Vaccinium myrtillus																
Vaccinium scoparium																
Viburnum edule															1	
Viola rugulosa													1			
Achillea millefolium	2	5	2	3	3	3		2					3			
Arctostaphylus uva-ursi						+										
Arnica cordifolia			3	2						3			5		15	
Betula sps.	10	20	5		10	15	5									1
Cornus canadensis				3					10	3	3		5		20	10
Delphinium glaucum		3	3	5	1			10								
Epilobium angustifolium	3	5	1	10	1	3		3	+				3		5	5
Equisetum arvense			5													+
Equisetum scirpoides	1															
Equisetum sylvaticum	3	1	10	5	1	3										
Fragaria vesca	5	3	1	3	1	3		5								
Galium boreale	5	5	2	5	3	2	1	3		2						
Geocolon lividum						3										
Geum rivale	5			3	3	3		10								
Grass sps.		5	1	10	2	20		10	3				3	5	5	3
Heracleum lanatum			+	10				1					+			
Lathyrus sps.		2								3						
Ledum groenlandicum			1						25	40	35	10	60			30
Linnaea borealis			5	1					4	10		3	5		3	
Lonicera involucrata			1	15									2			
Mertensia paniculata	5	5	3		3	1		2		1					2	
Mitella nuda	3		5	5	3	1										
Pedicularis racemosa								2								5
Petasites palmatus		5	10			2		3		2			3			5
Picea mariana			1	+				1	2	2					1	1
Ribes sps.			1	5								+				1
Rosa acicularis		5	3							3	+		2	5	3	2
Rubus acaulis	3						1									
Rubus pedatus			1		2	3					1		3			
Salix sps.	90	25	40	15	40	15	10	24	+	+			+			1
Sedge sps.	30	5	1		5		30									
Shepherdia canadensis			+							1						
Streptopus amplexifolius		2										+	3		+	1
Vaccinium caespitosum						3										
Vaccinium vitis-idaea			5	1					20	5	10	5	5			10
Viola adunca	1												3			

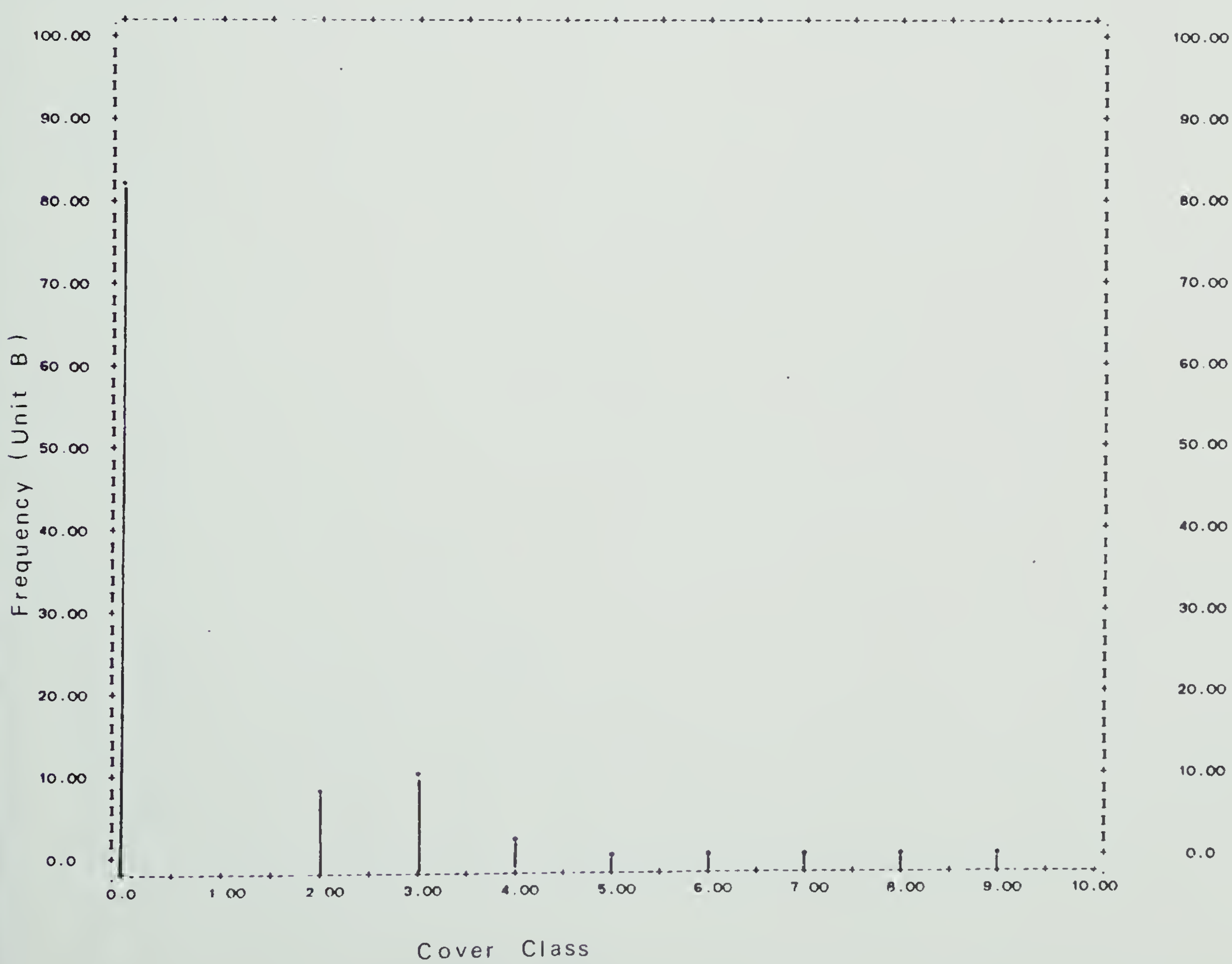
	GROUP B																																	
	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	36	39	41	43	44	45	46	47	48	50
Vaccinium myrtillus	5	30	3	5		5	5		5	5	2	5	10	10				5				2	1			2		1	1					10
Vaccinium scoparium						2																												
Viburnum edule		+																																
Viola rugulosa	+														3																			
Achillea millefolium	1									1									1						2									
Arctostaphylus uva-ursi																										3		5						
Arnica cordifolia	3	5	2	3	10	5	1		5			2			3	10	15			3	10				5	+							1	5
Betula sps.	3							3		3	5										+	+		3										
Cornus canadensis	10	10	5	5	5	10	5	5	5	5	5	5	5	10	15	10	5	10	5	15	3	10	5	10	15	3	5	5	5			5		10
Delphinium glaucum					5																													
Epilobium angustifolium	3	1	+	+	5	1	+	3		2	3	1		3	5	3	5	5	2		5					2		1					1	2
Equisetum arvense																																		
Equisetum scirpoides										5																								
Equisetum sylvaticum								10		10	3	+											30	3		1						1		
Fragaria vesca										3								2								1								
Galium boreale	+									3																2								
Geocolon lividum							1																											
Geum rivale																							1											
Grass sps.	10	5	10	10	11	5	3	2	5	5	2	1	1	2	5	2	5	10	5	2	4	5	2		3	5	3	3	1	1			3	1
Heracleum lanatum					+																		+											
Lathyrus sps.																										5								
Ledum groenlandicum	10	+				35	25	10	20	7	10	20		10	+	25		+		5		40	3	50	20	5	10		7			45		
Linnaea borealis	3		5		3	3	5		3	2	1	1	2	3	5	2	5	2	1	5	3	2			10	3		5	5			2	5	
Lonicera involucrata	1									5													3											
Mertensia paniculata					5					3																								1
Mitella nuda										3																								
Pedicularis racemosa	2	5			3	1	1															4												
Petasites palmatus	2						2	3	5	5	3						2						1		3	1								1
Picea mariana							5	5		3		2											5				5		10					
Ribes sps.					1					1			+	+						+		+								+				2
Rosa acicularis	5	3	10	3			3		5	3		3							+		1	3	5			3			3	1			5	
Rubus acaulis	3									5				3					+				2			3								
Rubus pedatus													5	5	15	3	3			2				3	2							5	2	5
Salix sps.	2				1		+	2	+	2	2						1	3	15			1	3		5	+								3
Sedge sps.								4		2																								
Shepherdia canadensis																										+								
Streptopus amplexifolius			+		5		1						2	2	3					2				3						1		1		1
Vaccinium caespitosum																											3		5					
Vaccinium vitis-idaea	10	20	1	10		5	3	3	3	2	1	3	1		5	5	5	2			+	10	5	10	10	5	5	5	5	10		5	2	5
Viola adunca		3																																

Appendix 4 - Frequency Distributions

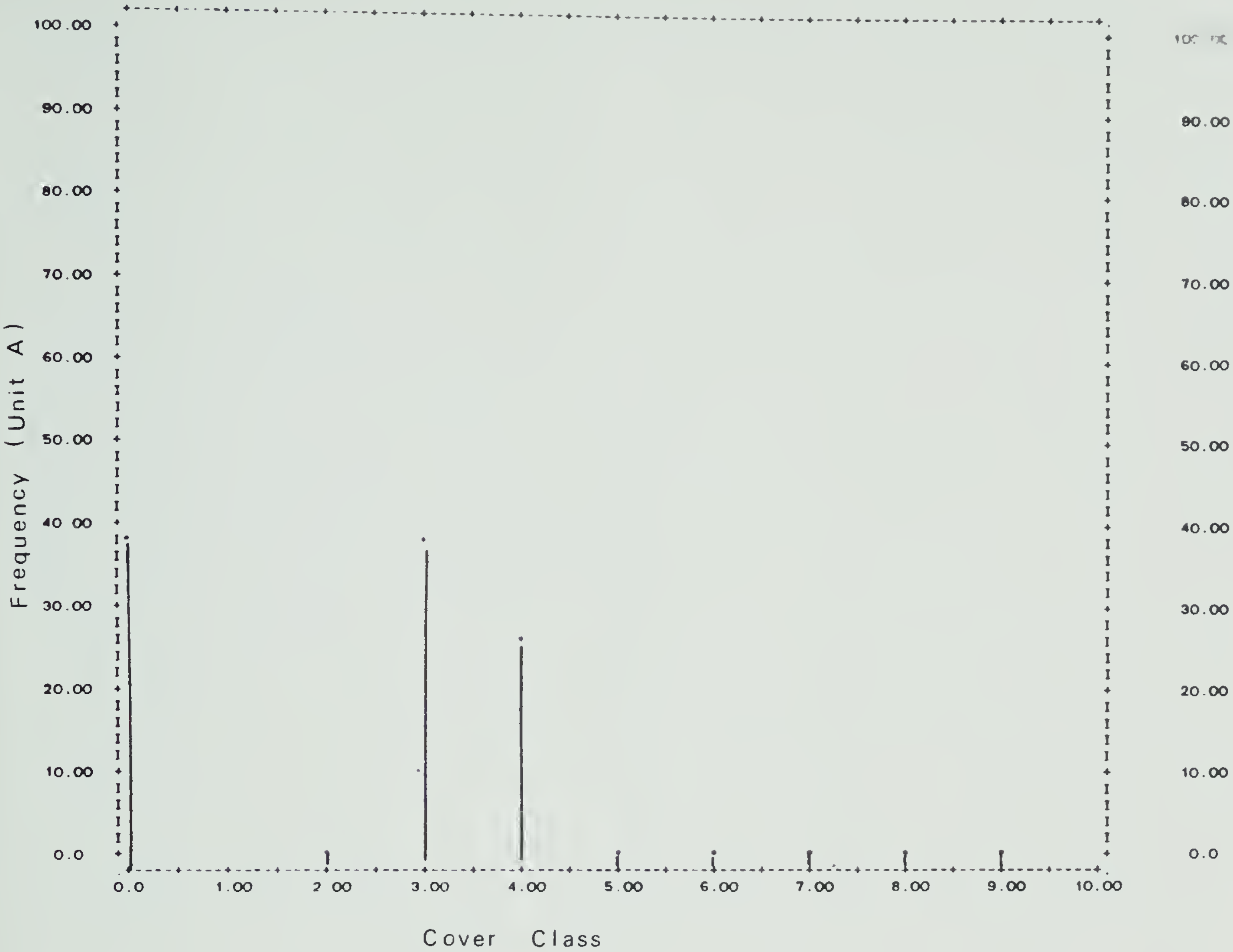
COVER DISTRIBUTION - BETULA



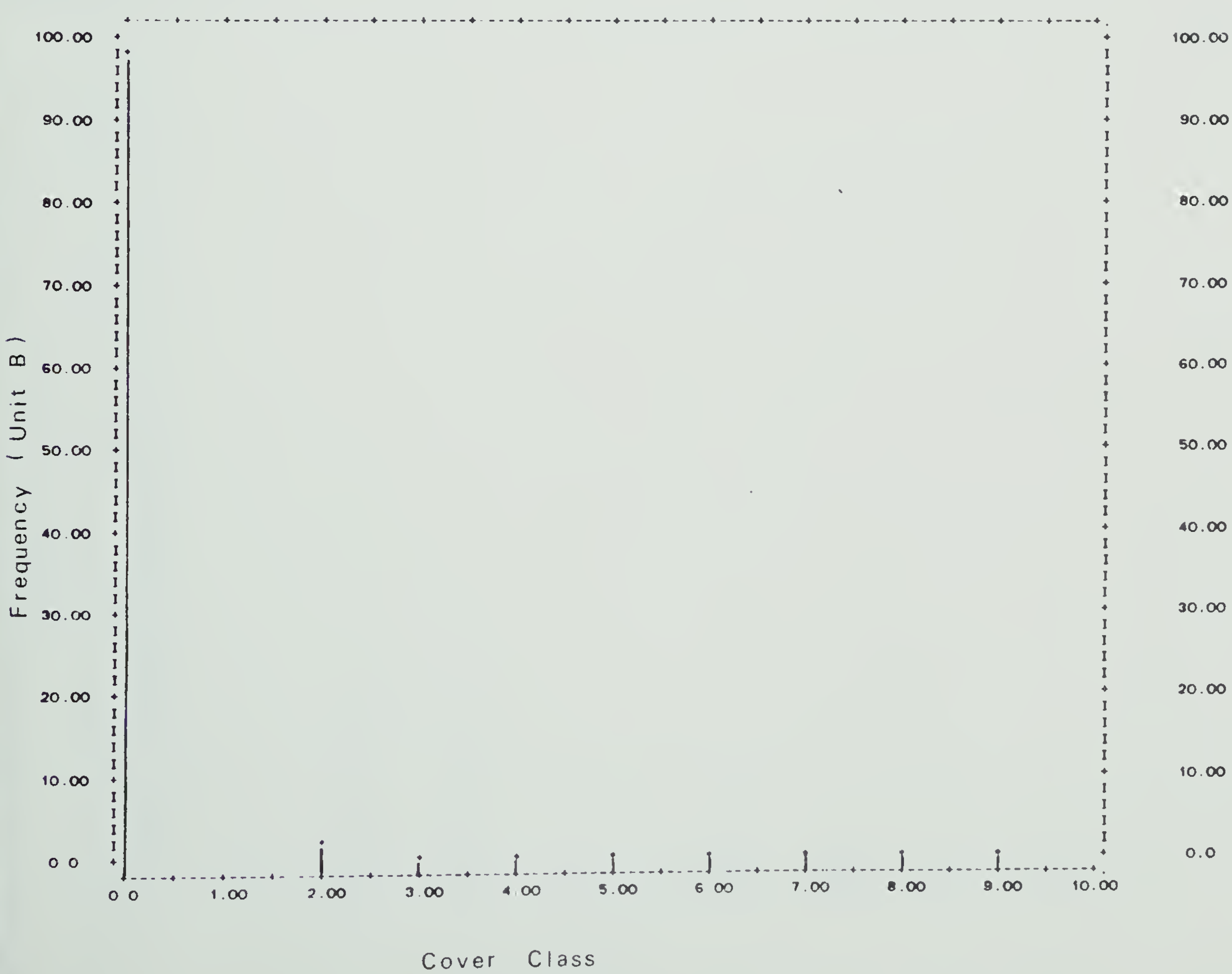
COVER DISTRIBUTION BETULA



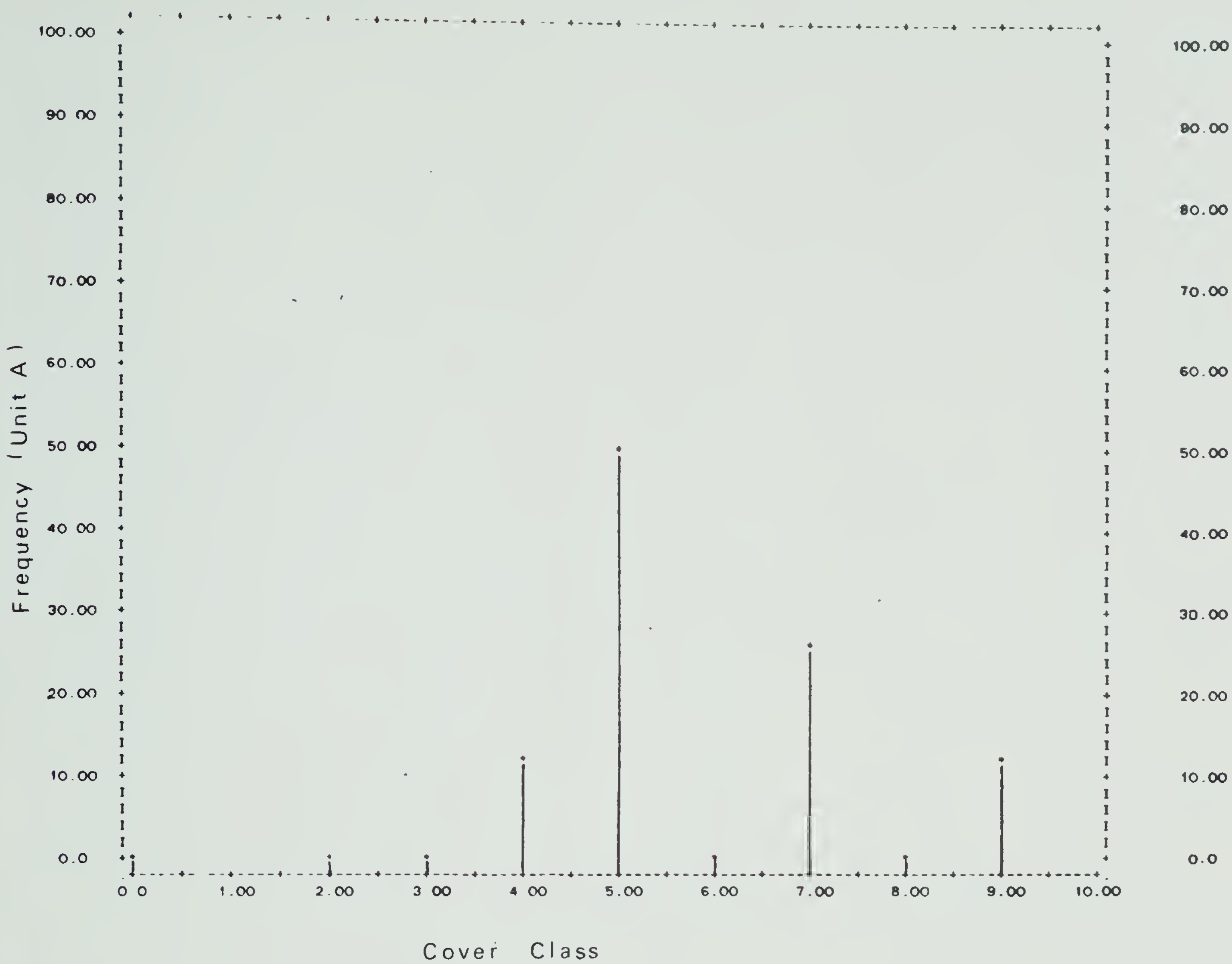
COVER DISTRIBUTION - GEUM



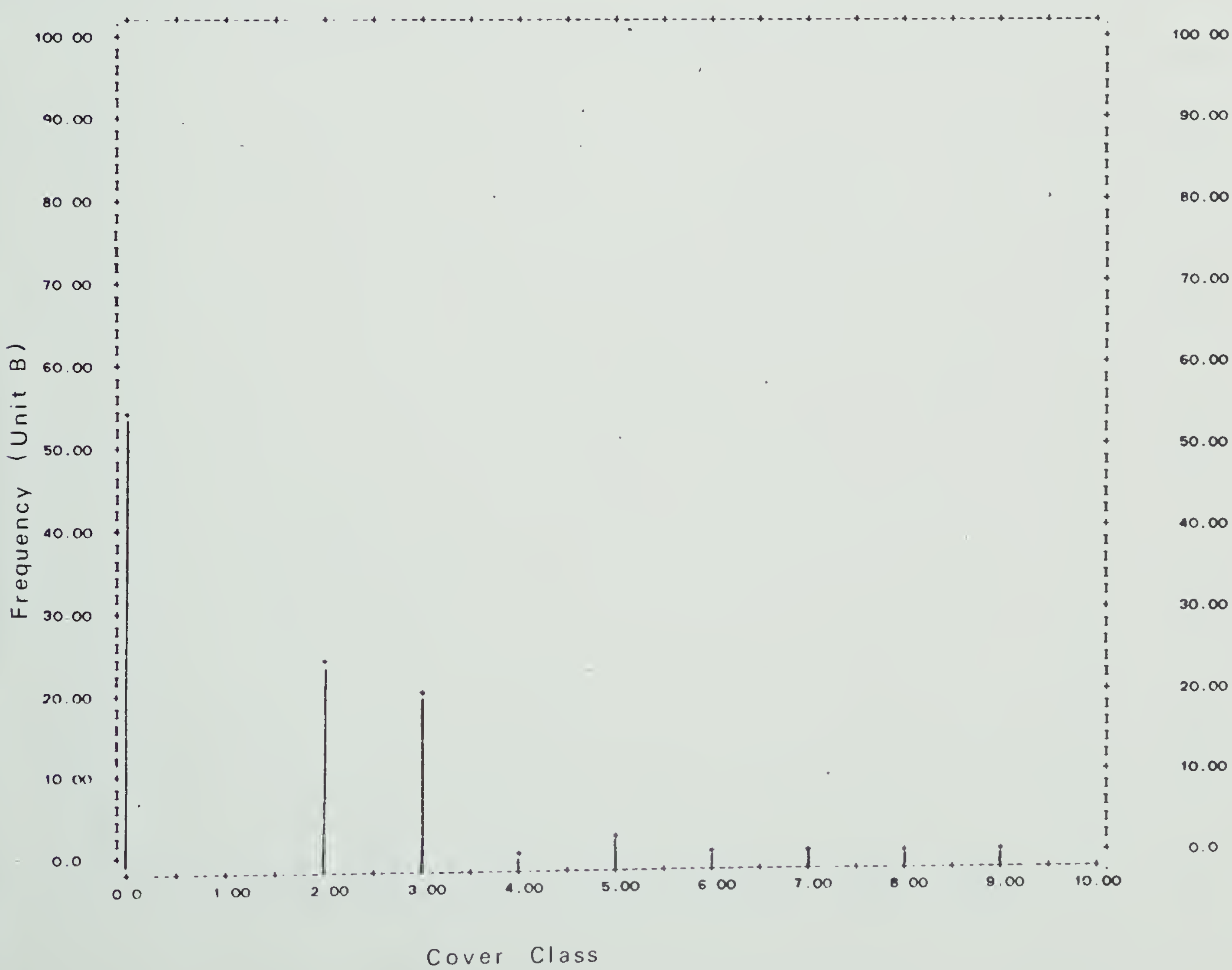
COVER DISTRIBUTION - GEUM



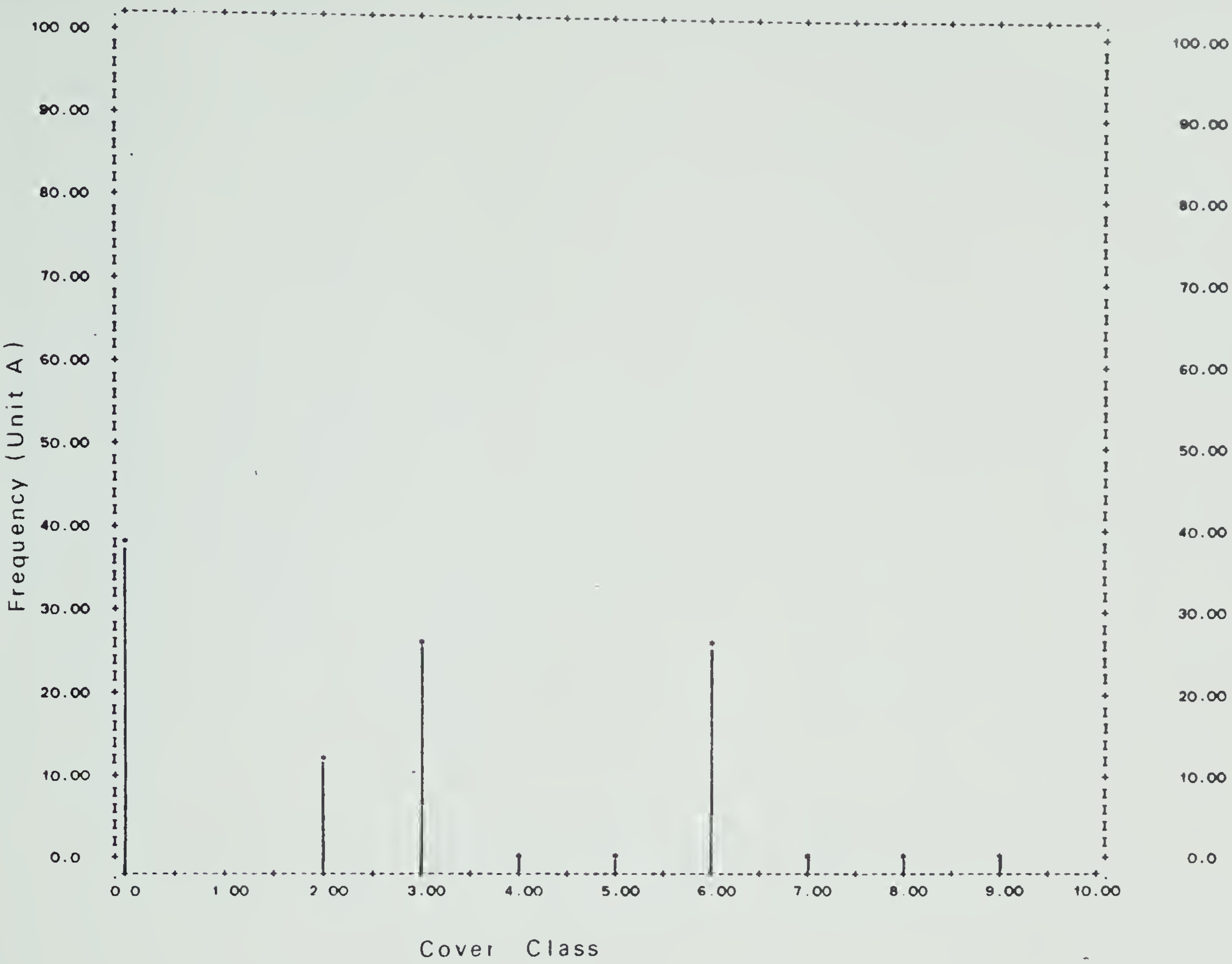
COVER DISTRIBUTION SALIX



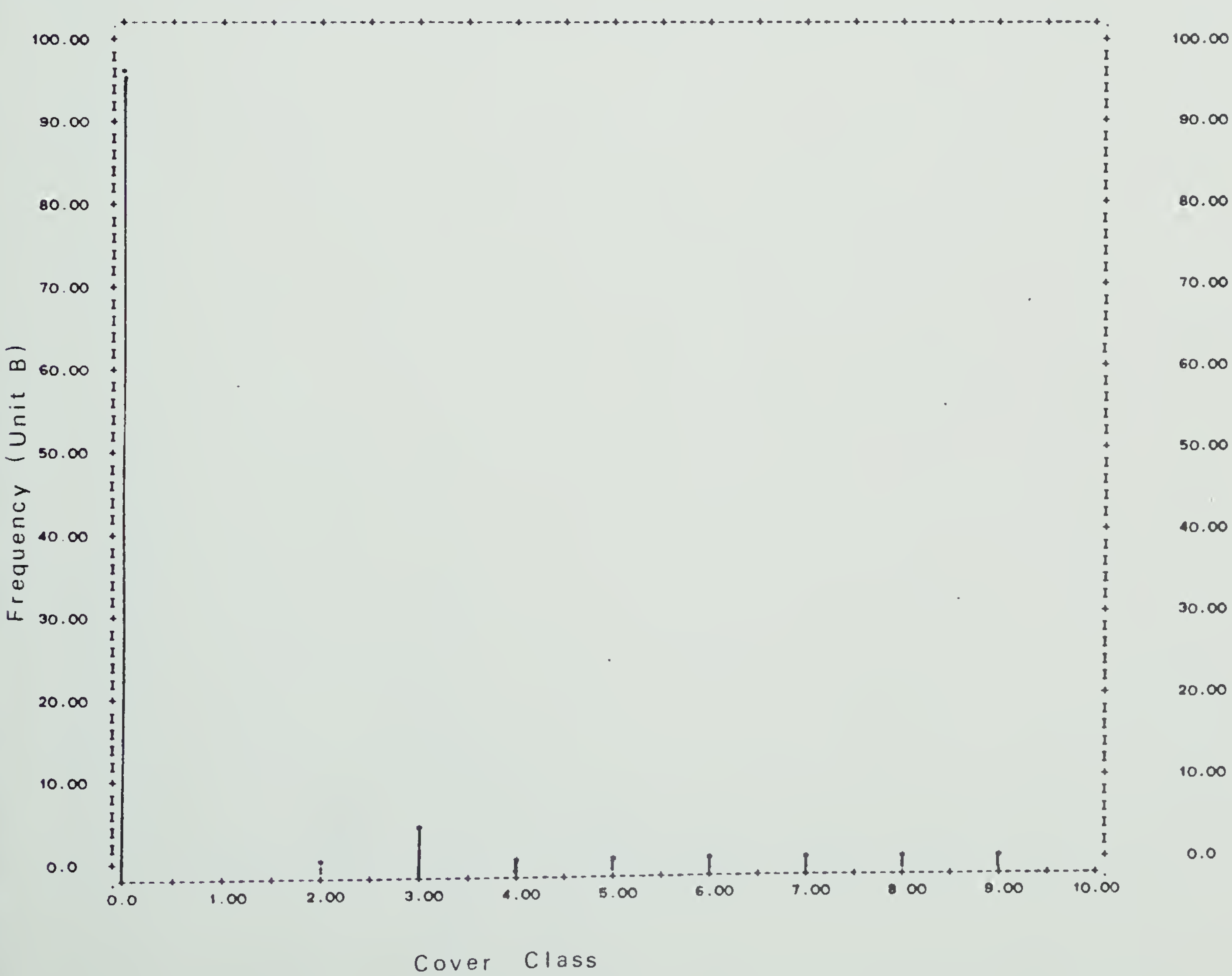
COVER DISTRIBUTION - SALIX



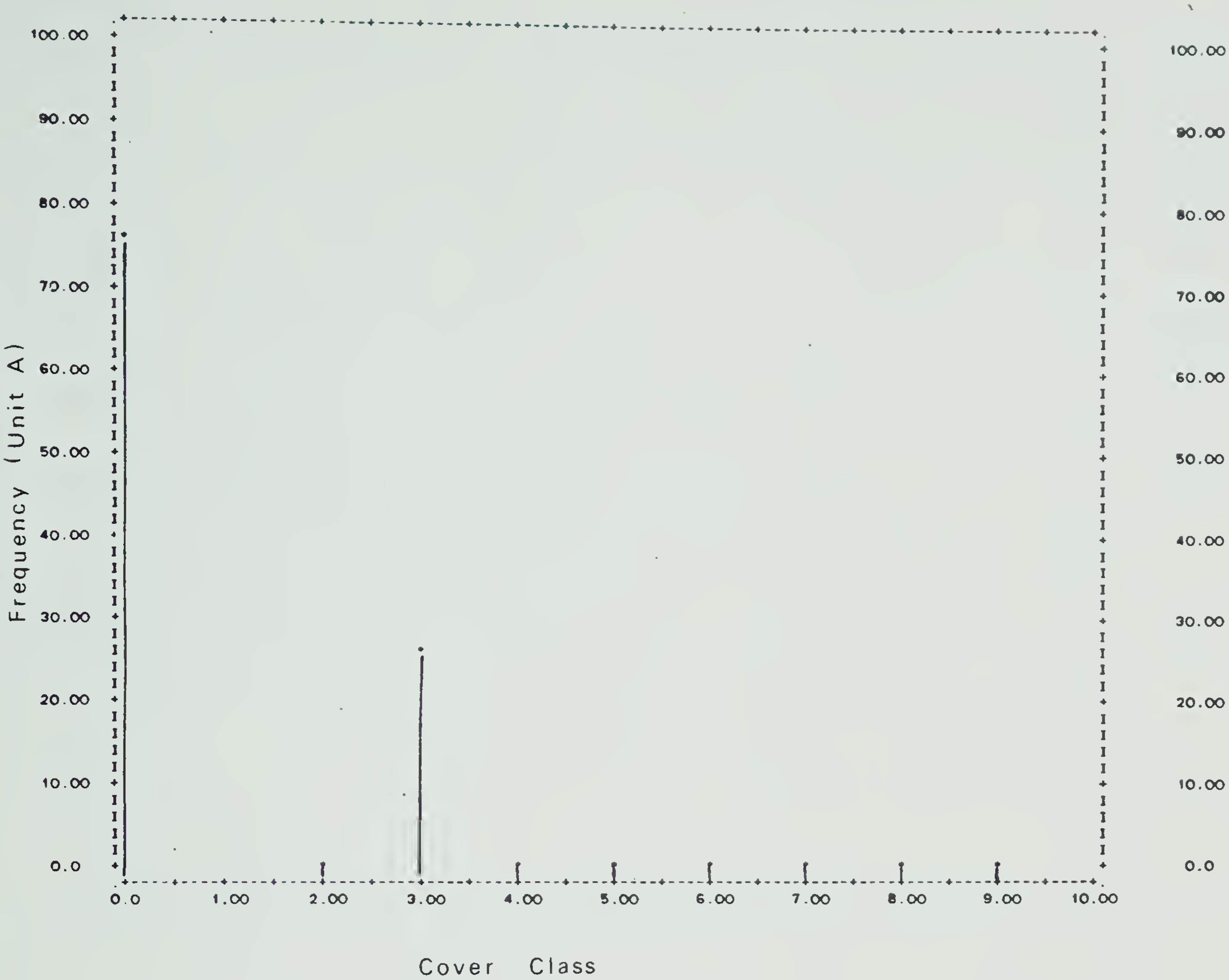
COVER DISTRIBUTION - SEDGE



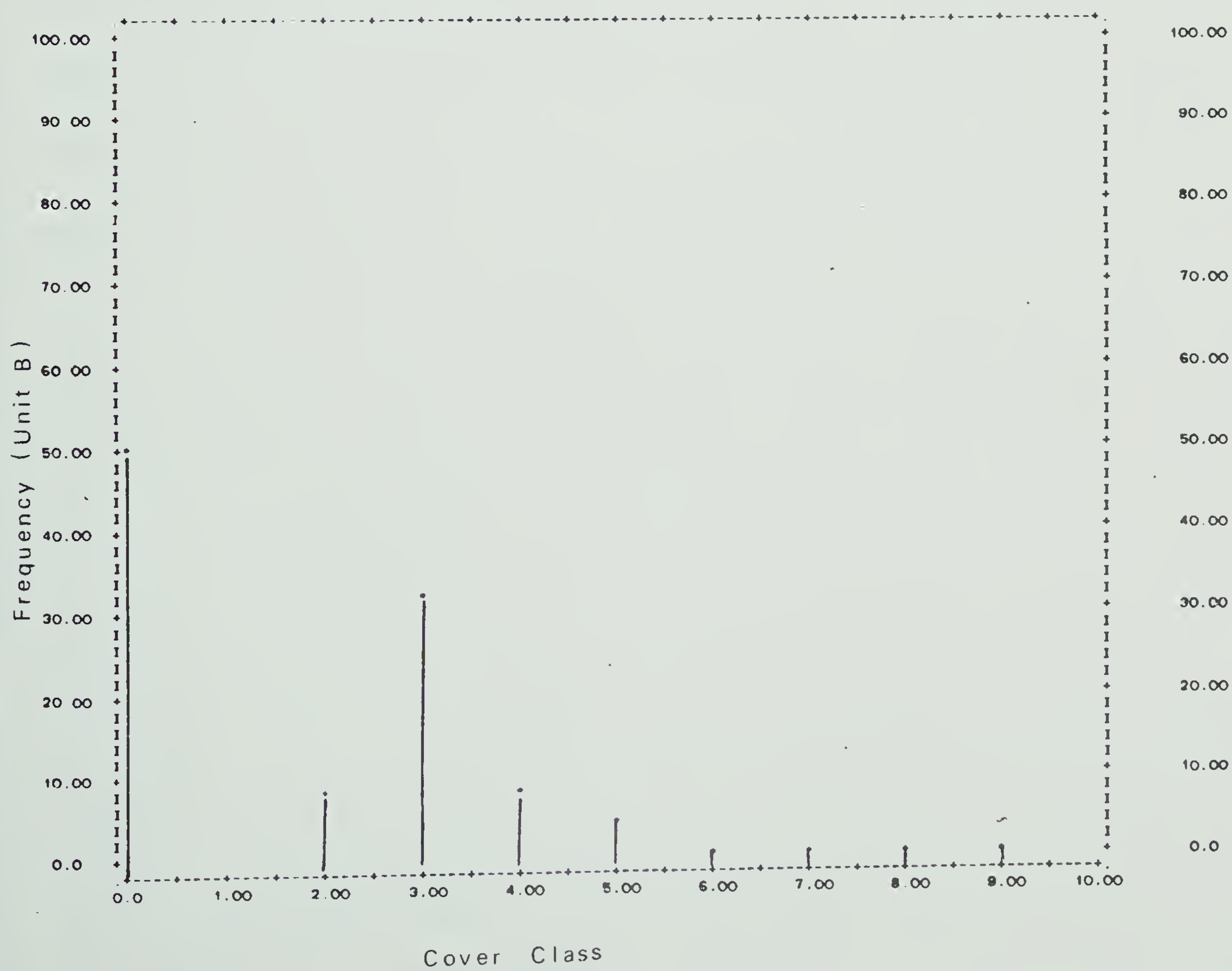
COVER DISTRIBUTION - SEDGE



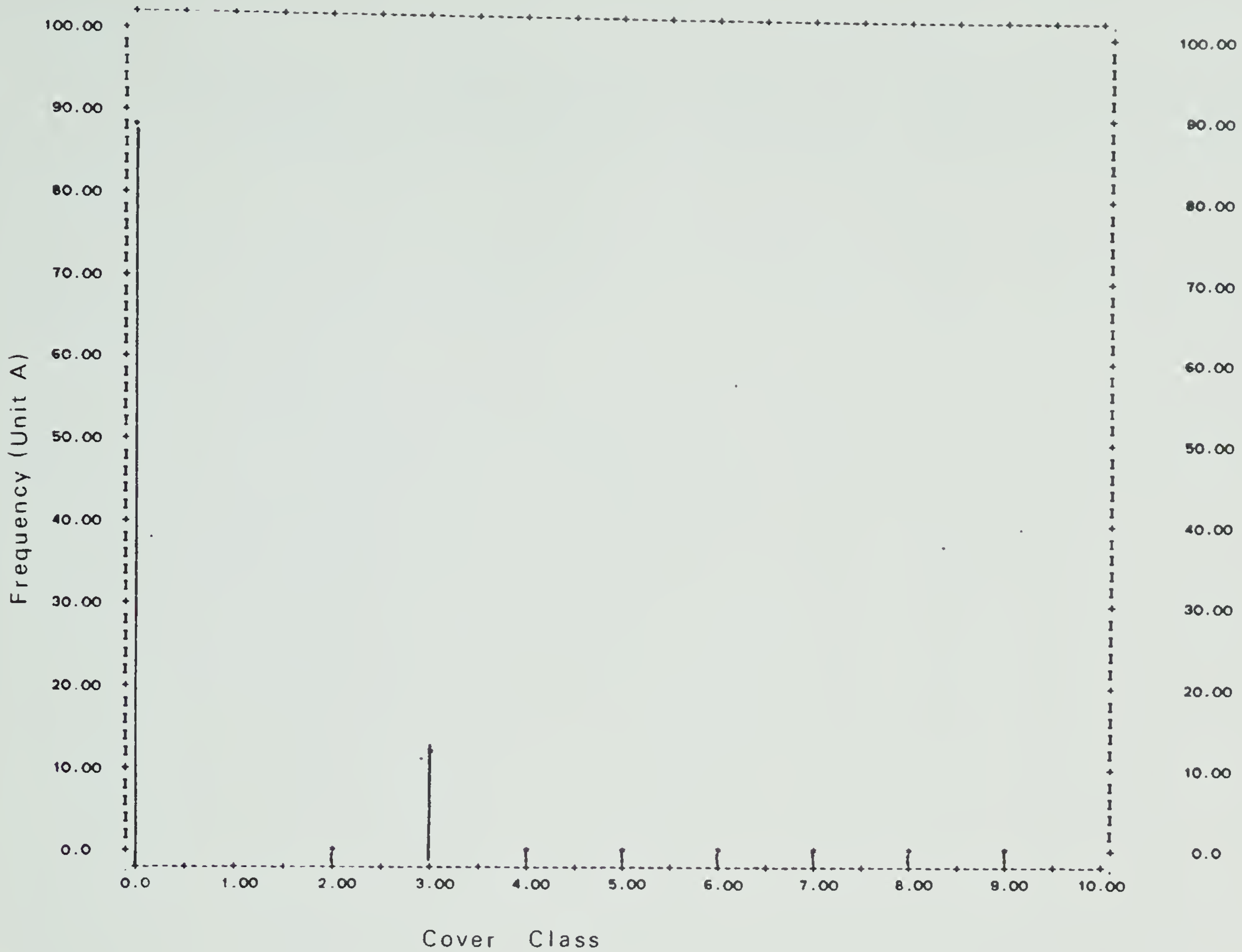
COVER OISTRIBUTION - ARNICA



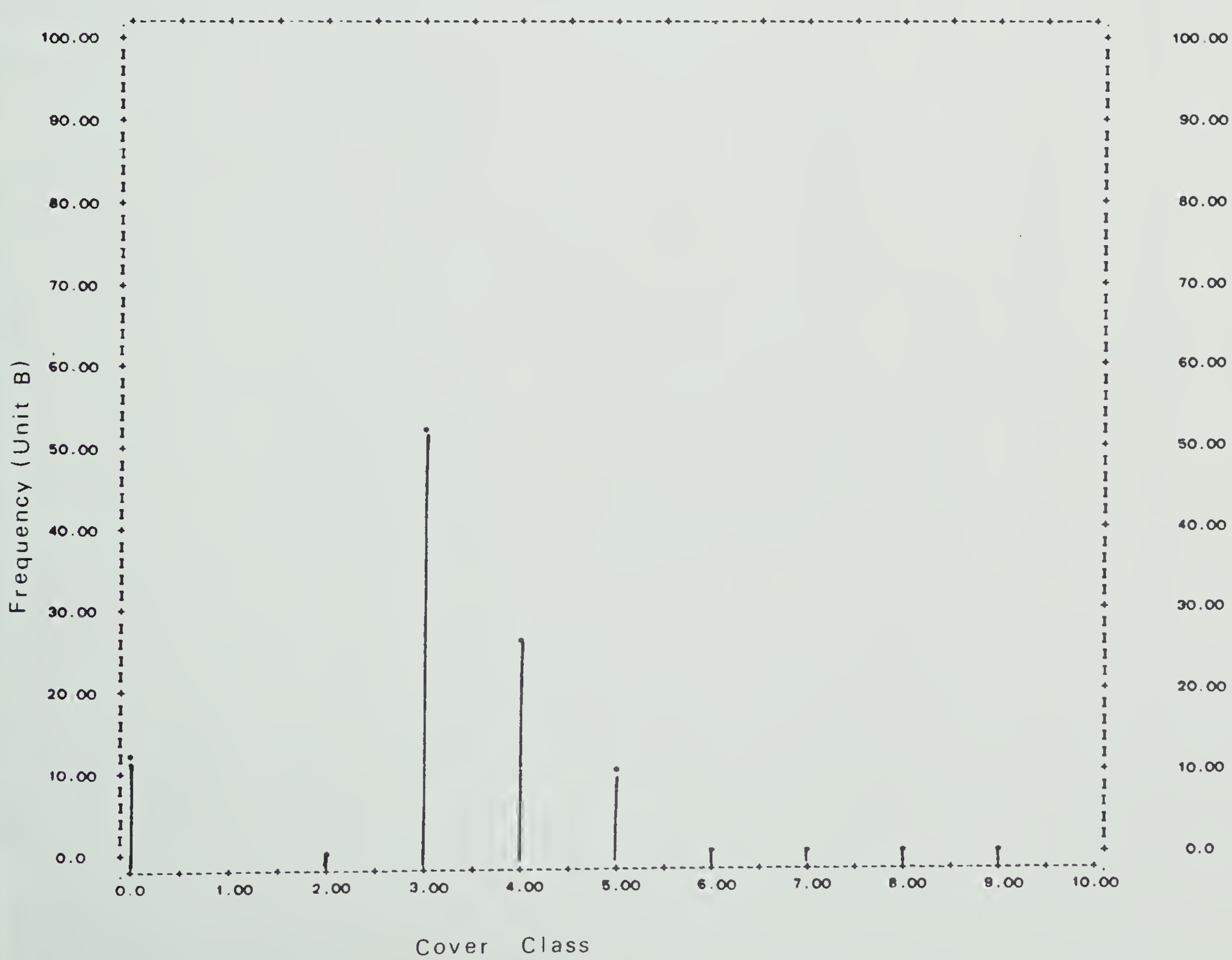
COVER OISTRIBUTION - ARNICA



COVER DISTRIBUTION - CORNUS



COVER DISTRIBUTION - CORNUS



Appendix 5 - Data Used in Rational Formula Calculations

Spring Data for Stormflow Prediction at Tri Creeks, Alta.

Qact cfs	i in/hr	Aact acres	Aest acres	Ppt in	Ant.P. in	Ant.P./Day in/day	#Days from May 1	Storm Duration
10.7	0.05	800		0.26	0.34	0.08	57	5.2
9.6	0.03	800		0.39	0.01	0.01	46	13.0
42.6	0.04	800		0.25	0.75	0.75	47	6.3
11.6	0.06	800		0.32	0.03	0.03	58	5.3
49.9	0.07	800		0.48	0.49	0.49	37	6.9
62.9	0.03	800		0.16	0.35	0.35	6	5.3
9.9	0.04	800		0.15	0.17	0.08	27	3.8
12.5	0.03	800		0.35	0.40	0.06	20	11.7
42.2	0.04	800		0.27	0.36	0.36	11	6.8
67.4	0.05	800		0.23	0.08	0.04	20	4.6
7.9	0.02	350		0.19	0.27	0.09	56	9.5
7.1	0.03	350		0.24	0.73	0.73	44	8.0
12.8	0.04	350		0.16	0.0	0.0	44	4.0
30.1	0.04	350		0.33	0.21	0.21	37	8.3
10.0	0.11	350		0.42	0.92	0.18	57	3.8
11.1	0.03	350		0.17	0.18	0.06	18	5.7
7.6	0.04	350		0.32	0.41	0.41	20	8.0
25.1	0.04	350		0.87	0.24	0.12	28	21.8
62.9	0.06	350		0.55	0.59	0.59	16	9.2
38.1	0.03	350		0.20	0.30	0.30	6	6.7
9.7	0.04	450		0.38	0.0	0.0	36	9.5
16.2	0.05	450		0.26	0.10	0.05	45	5.2
5.8	0.10	450		0.62	0.99	0.49	47	6.2
9.4	0.05	450		0.64	0.32	0.10	59	12.8
10.8	0.06	450		0.28	0.46	0.23	57	4.7
71.8	0.06	450		0.55	0.73	0.73	16	9.2
3.7	0.14	450		1.42	0.81	0.41	6	10.1
6.9	0.03	450		0.34	0.19	0.09	13	11.3
5.5	0.04	450		0.19	0.33	0.11	18	4.8
28.4	0.03	450		0.19	0.37	0.37	6	5.3

Summer Data for Stormflow Prediction at Tri Creeks, Alta.

Qact cfs	i in/hr	Aact acres	Ppt in	Ant.P. in	Ant.P./Day in/day	# Days from May 1	Storm Duration
8.8	0.03	800	0.28	0.20	0.20	131	9.3
22.6	0.05	800	0.66	0.48	0.24	140	13.2
34.5	0.06	800	1.04	1.54	0.30	133	17.3
2.8	0.03	800	0.31	0.17	0.08	116	10.3
28.2	0.05	800	0.52	0.56	0.56	115	10.4
10.1	0.11	800	0.65	0.65	0.16	101	5.9
13.6	0.04	800	0.21	1.53	0.38	112	5.3
10.8	0.08	800	0.39	0.12	0.03	74	4.9
19.4	0.04	800	0.60	1.90	0.17	66	15.0
11.9	0.05	800	0.27	0.96	0.12	88	5.4
4.5	0.02	350	0.14	0.09	0.09	137	7.0
13.2	0.04	350	0.72	0.0	0.0	151	18.0
27.0	0.06	350	1.09	1.55	0.38	133	18.2
1.0	0.02	350	0.21	0.15	0.04	110	10.5
22.2	0.06	350	0.61	1.38	0.46	109	10.2
11.5	0.06	350	0.42	0.64	0.12	117	7.0
10.0	0.03	350	0.20	2.46	0.35	112	6.7
2.6	0.02	350	0.17	0.37	0.12	90	8.5
11.6	0.04	350	0.52	0.63	0.12	66	13.0
29.4	0.10	350	1.43	1.27	0.18	72	14.3
21.0	0.06	450	1.03	1.55	0.31	133	17.2
12.3	0.03	450	0.50	0.22	0.07	151	16.7
2.6	0.02	450	0.23	0.10	0.10	130	11.5
7.1	0.06	450	0.49	0.84	0.42	109	8.2
9.4	0.02	450	0.17	0.45	0.15	107	8.5
13.4	0.06	450	0.51	0.76	0.76	109	8.5
4.0	0.03	450	0.28	0.12	0.12	110	9.3
8.8	0.02	450	0.11	0.96	0.12	88	5.5
29.7	0.07	450	1.36	1.32	0.26	67	19.4
2.7	0.02	450	0.22	0.18	0.18	90	11.0

Appendix 6 - Correlation Matrix

	QACT	I	AACT	P	ANP	ANPD	T	D
QACT	1.00000	0.57469	0.18295	0.83218	0.57283	0.44585	-0.02348	0.58250
I	0.57469	1.00000	0.21482	0.69998	0.30397	0.26644	-0.24580	0.11279
AACT	0.18295	0.21482	1.00000	-0.05071	0.01510	0.05000	-0.03792	-0.18298
P	0.83218	0.69998	-0.05071	1.00000	0.41552	0.23185	-0.07120	0.74387
ANP	0.57283	0.30397	0.01510	0.41552	1.00000	0.47397	-0.22364	0.17675
ANPD	0.44585	0.26644	0.05000	0.23185	0.47397	1.00000	0.06183	0.00644
T	-0.02348	-0.24580	-0.03792	-0.07120	-0.22364	0.06183	1.00000	0.21200
D	0.58250	0.11279	-0.18298	0.74387	0.17675	0.00644	0.21200	1.00000

QACT = gauged flow
I = precipitation intensity
AACT = mapped contributing area
P = precipitation

ANP = antecedent precipitation
ANPD = antecedent precipitation per day
T = time from May 1
D = storm duration